University of Alberta

Economics of Priority-use Zoning

by

Jay Anthony Anderson ©

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in

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ABSTRACT

This three-paper thesis explores the economics of priority-use zoning at three different scales: the stand-, forest-, and international-level. The first paper (Chapter 2) is the stand-level analysis. Here we estimate a yield curve for hybrid poplar, and use it to conduct a financial analysis of hybrid poplar plantations. Our findings suggest hybrid poplar plantations in Alberta are barely financially viable. Before these plantations could play a role in priority-use zoning, the financial viability would likely need to be improved. Such improvements could occur through changes to land-use policy.

The second paper (Chapter 3) is the forest-level analysis. Here we assess how current forest policies for Canada's private and public land may constrain plantation forestry, and therefore prevent priority-use zoning. We suggest policies that could encourage zoning within Canadian boreal regions. Then we use a timber supply model to analyze how each policy affects forest industry profits, timber output, and the spatial allocation of forest preserves. Our findings suggest the policies give rise to priority-use zoning, thus enabling land-use specialization to increase both profits and preservation.

The third paper (Chapter 4) is the international-level analysis. Here we further explore priority-use zoning by empirically analyzing the following determinants of forest preservation: income, trade, institutions, technique (i.e., plantations), as well as the composition and scale of the economy. Our findings suggest that a country's preservation is affected by its polity, level of forestry imports, and income—but not by its plantation area (suggesting a paucity of priority-use zoning). We also find evidence that forest preservation is higher in more democratic countries and in countries that import more forest products.

DEDICATION

To Lynnette

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CHAPTER 1.INTRODUCTION

Background

Canada's boreal forestry sector faces a number of challenges. First, there is increasing competition among land uses and users. For example, interpreting historic rights of Aboriginal Peoples to forests is an ongoing process, in some cases having major potential implications for industrial forestry (Stevenson and Webb 2003). Moreover, non-timber interests, including recreation and biodiversity values, are becoming increasingly influential in forest management plans. Along these lines, some believe current land-use policies in Canada fail to protect enough land as biological reserves, thus leading to a decrease in biodiversity that may compromise future non-timber values (e.g., Hunter 1999, Larsson and Danell 2001). These concerns are being voiced by an international constituency who has had substantial success in curbing harvest in other jurisdictions, such as the United States (Limerick 2002). Meanwhile, some provincial forests are being heavily impacted by oil and gas production. For example, simulations for a study area in northeastern Alberta suggest that the energy and forestry industries could increase the density of human-origin edge from 1.8 to 8.0 km/km^2 (Schneider et al. 2003).

The second challenge facing the Canadian forestry sector is that the global industry appears to be undergoing significant changes. Forest fibre production is rapidly evolving from timber foraging to a system of agricultural cropping (Sedjo 1999). Although global harvest from industrial plantations was negligible as late as the 1950s, by 2000 it had risen to an estimated 34%, with 10% of this harvest made up of exotic tree species (Sedjo 2003). It is expected that the share of timber from industrial plantations will continue rising to between 50 and 75% by the year 2030 (FAO 2000). If such predictions become reality, a firm's survival may depend on access to low cost fibre from industrial plantations on main roads close to mill sites.

The third challenge is that the boreal forest does not represent a high value fibre resource relative to other types of forests and other types of resources (e.g., oil and gas). Existing trees are small, relative to those in coastal forests, and growth rates are low (e.g., Sedjo 1999, Tomberlin and Buongiorno 2001). As such, stumpage fees collected by governments are frequently dwarfed by other revenue sources, and government costs of administering forestry operations on these lands sometimes exceed stumpage revenues that governments collect. For instance, in 2005-06 the Alberta government's oil and gas management expenses of $132 million are estimated to yield revenues of $7.67 billion from this sector; whereas government timber management expenses of $139 million are only expected to yield stumpage revenues of $81 million (Ministry of Finance 2005).

These three challenges lining up simultaneously have the potential to turn into the "perfect storm" for Canada's forest industry. In the United States, it only took a small subset of these conditions (i.e., spotted owls and below-cost timber sales) to reduce harvests on western federal forests in 1995 to 15% of what they were in 1988 (Wear and Murray 2004). Considering that Canada has approximately 95% of its forests on public lands, the suite of conditions currently brewing among various interested segments of the public make the challenges facing the forest industry seem significant.

A potential solution

In the face of these challenges, a potential solution is to implement a priority-use zoning system which has intensive forest management as a component. Such an approach is intuitively appealing as it could address all three problems. First, if intensified forest management produces more annual volume per hectare, then there would be the potential to maintain current harvest levels while freeing up forested land currently under industrial use for competing uses, such as ecological preservation. It can also be argued that such a strategy is in line with global trends towards plantations, and is necessary for the Canadian forest industry to maintain its global competitiveness. Indeed, such practices could increase the value of the forest resource by increasing growth rates and locating timber on main roads close to mill sites.

This form of priority-use zoning uses the increased productivity of plantations to maintain timber production while at the same time increasing preservation (e.g., Messier 2007). One such form of priority-use zoning is known as triad (e.g., Hunter and Calhoun 1996). As the name suggests, a triad system is comprised of three different management zones: intensive, extensive and protected. Intensive zones are managed as short rotation industrial plantations; extensive zones are managed for multiple uses by allowing native species to naturally regenerate over long rotations; and preservation zones are withdrawn from the industrial land base to act as biological reserves.

Generally speaking, priority-use zoning systems can have any number of different land-use zones, and any number of different objectives. The major objective of triad is to create new preservation zones without eliminating forestry jobs or output (Gladstone and Letig 1990, Hunter and Calhoun 1996, Binkley 1997). Triad acknowledges that a particular hectare of land cannot be all things to all people. An old growth forest, once converted to a normal forest with a 70-year rotation, will no longer provide old growth habitat. In other words, managing all lands for all outputs may not only inappropriately supply both timber and non-timber values, it might also inefficiently deploy management inputs (Vincent and Binkley 1993). The land-use specialization accomplished through zoning may be a solution to these inefficiencies.

Unfortunately, financial considerations often spoil otherwise good ideas. Achieving a financially feasible intensive zone in Canadian boreal regions is difficult at the stand-level (Rodrigues et al. 1998) and may condemn priority-use zoning. The large initial investment required in relation to the relatively low productivity gained from *native species* results in negative soil expectation values (SEVs) (Rodrigues et al. 1998), thus making such investments financially infeasible. Accordingly, it may be difficult for forestry firms to justify allocating land to an intensive zone using financially infeasible silvicultural systems.

There are, however, many silvicultural systems, and thus many ways to implement priority-use zoning. To become feasible, intensive zones may simply require different trees—ones that grow fast enough to give firms the financial incentive to make the large capital investments required for intensive forest management. Hybridized varieties of poplar, aspen and willow may be those trees (Weih 2004). Yet few firms in Canada's boreal regions are pursuing the global trend of establishing fast growing exotic plantations. It is possible that policy reform could make plantation forestry, and hence priority-use zoning, feasible. This thesis explores such a possibility—at both the stand- (Chapter 2) and forest-level (Chapter 3).

Finally, in Chapter 4 we look beyond Canada's borders for international evidence of a correlation between plantations and preservation. The forest economics literature is rife with multi-country analyses that correlate certain factors with deforestation (Rudel 1989, Cropper and Griffiths 1994, Deacon 1994, Naidoo 2004, etc.), as well as survey papers compiling these results (van Kooten et al. 1999, Barbier and Burgess 2001, Angelsen and Kaimowitz 2001, etc.). Using similar econometric methods, we investigate whether there appears to be a relationship between forest preservation and forest intensification, since this would suggest that some countries are using plantations to offset timber losses from forest preservation.

Thesis structure

- In Chapter 2 we conduct a stand-level analysis of whether intensive management of hybrid poplar on private land in boreal regions is financially viable.
- In Chapter 3 we conduct a forest-level analysis identifying possible policy constraints to plantation forestry, and suggesting policy alternatives that might alleviate these constraints. We then use a spatial timber supply model to evaluate these policy alternatives.
- In Chapter 4 we conduct an international-level econometric analysis of the determinants of forest preservation. Our focus is whether forest preservation appears to be correlated to the intensification of forest management.
- In Chapter 5 we summarize our findings and offer some general conclusions.

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CHAPTER 2. STAND-LEVEL ANALYSIS[1]

Introduction

As previously mentioned, the triad[2] form of priority-use zoning requires a zone of intensive forest management. In this case, the increased productivity of plantation forestry could maintain current harvest levels while freeing up forested land currently under industrial use for competing uses, such as ecological preservation (e.g., Messier 2007). Plantation forestry could also increase the global competitiveness of Canada's forestry sector by increasing the value of the forest resource.

However, plantation forestry in the boreal forest using native tree species is not believed to be financially viable at the stand level (Rodrigues *et al.* 1998). Intensive zones require trees that grow fast enough to give firms the financial incentive to make the large capital investments required for intensive forest management. Hybridized varieties of poplar, aspen and willow grow faster than native trees in boreal regions, and are thought to be a better species to use in plantations (Weih 2004).

In fact, some researchers have predicted the 21st century to be the "era of tree domestication", and that "poplar will lead the way" (Bradshaw and Strauss 2001). Much of the interest in poplar results from its vegetative propagation abilities. With stem cuttings, superior hybrids can be easily and quickly cloned and, within a short time, made available for planting on a large scale (Heilman 1999). But the most recent empirical study we found to support this opinion—a paper by Peterson *et al.* (1970)—is over thirty years old and does not consider financial viability.

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[1] A version of this chapter has been published. Anderson, J.A. and M.K. Luckert. 2007. Can hybrid poplar save industrial forestry in Canada?: A financial analysis in Alberta and policy considerations. The Forestry Chronicle 83(1):92-104.

[2] Triad is a priority-use zoning system consisting of three different management zones: intensive, extensive and preserved. Intensive zones are managed as short rotation industrial plantations; extensive zones are managed for multiple uses by incorporating native species under longer rotations; and preserved zones are withdrawn from the industrial land base to act as ecological preserves.

One way to gain insights into using hybrid poplars for fibre production is to consider potential areas of the expansion of hybrid poplar plantations. Tardif (1994) reports that of Canada's 67.8 million hectares of agricultural lands, 21 million hectares are considered to be marginal lands (i.e., of borderline profitability when used for agriculture) and may therefore be considered usable for hybrid poplar.[3] Close to 80% of these marginal areas are located in British Columbia and Alberta.

Yet few firms are pursuing the global trend of establishing fast growing industrial plantations. For example, we know of only one firm in Alberta, Alberta-Pacific Forest Industries Inc., that is operationally (i.e., not for research purposes) establishing private-land plantations of exotic species, with plans to establish 25 000 hectares of hybrid poplar plantations by 2020 (Thomas and Kaiser 2003). But the paucity of exotic plantations may not result from financial reasons alone. For example, Alberta has regulations strictly constraining the use of exotic species on public land,[4] as well as preventing foreign firms from purchasing private land for timber production.[5] Therefore, it is unclear to what degree financial considerations and/or policy constraints are impeding the spread of plantations.

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[3] Hybrid poplar need not only be relegated to the less productive agricultural lands. But as will be shown in the financial analysis, the land rents payable to lease agricultural land can be substantial. Higher quality agricultural land would attract higher rental rates, which could make it difficult for hybrid poplar to yield a positive return.

[4] Forests Act, Timber Management Regulations 60/73: 144.2 The Minister may establish rules governing the source and type of tree seed and vegetative propagules used to reforest public land. AR 60/91 s26;153/97
and
Standards for Tree Improvement in Alberta (Ref. T/037): Provides standards for deployment of improved trees onto public land.

[5] Agricultural and Recreational Land Ownership Act, Foreign Ownership of Land Regulations 160/79: 5(1) An ineligible person or foreign controlled corporation may take or acquire, directly or indirectly, an interest in… land consisting of not more than 2 parcels containing, in the aggregate, not more than 20 acres.

In order to inform the more general question of what hybrid poplar might do for the Canadian forest industry, this chapter begins with a stand-level financial analysis. Because the collection of yield data for hybrid poplar has largely been limited to the prairie provinces, and because commercial operations of hybrid poplar have largely been focused in Alberta, we develop our financial analysis based on an Alberta case study. Since this chapter is a financial analysis, it assumes the sole benefit of concern is commercial timber, and no considerations are made for non-timber values. We then present a number of potential policy considerations that could influence the future role that hybrid poplar plantations may play in Alberta and across Canada.

Methods

Although hybrid poplar has only recently attracted the attention of Canadian forestry firms, the Prairie Farm Rehabilitation Administration (PFRA), a division of Agriculture and Agri-Food Canada, has been conducting research on hybrid poplars for over 25 years. In this section, PFRA data is used to estimate a yield curve for hybrid poplar in western Canadian boreal regions. This yield curve is then used in a stand-level model to calculate optimal economic rotations (OERs) and associated soil expectation values (SEVs). The Results section contains analysis of the sensitivity of the OERs and SEVs to changing net stumpage values, land rental costs, silvicultural costs, discount rates, and stand yield parameters.

Data collection

To our knowledge, the best source of long-term growth and yield data for Canada's western boreal regions comes from the PFRA (2001), which has conducted numerous growth trials where rooted cuttings of various hybrid poplar clones were planted at different locations throughout Saskatchewan. These trials are located between 102 and 110 degrees longitude west of the Greenwich meridian and between 49 and 60 degrees latitude north of the equator. Each year, western Canadian boreal regions usually receive 350 to 450mm of rainfall and experience 140 to 170 frost-free days (Environment Canada 2004).

In 2001, PFRA measured hybrid poplar stands in 4, 15 and 25-year age classes. The data from these measurements were used to estimate the yield curve for this chapter. The PFRA's objective was to compare the performance of different clones. Thus for each of the three different age classes, the PFRA measured the diameter at breast height (DBH), height and percent survival and averaged the results for each of the clones evaluated in the particular study.[6] This averaging resulted in a single value for DBH, height and percent survival for each different clone in each age class.

The 4-year age class study, which was conducted at 5 different locations in rural Saskatchewan, was planted at various densities to determine the optimal stocking level for forestry applications. The 15-year age class study, which also incorporated conditions similar to forestry applications, entailed monitoring trees of 11 different clones planted in 3 different locations in Saskatchewan. This study had four outlier clones that suffered unusually high mortality. These outlier clones were not used in the yield curve estimation based on the assumption that PFRA conducted these projects as breeding trials, and these poor performing hybrids would likely be eliminated from future breeding. Finally, the 25-year age class study was a three-row shelterbelt application with spacing equivalent to a 1000 stem per hectare planting. In this case, rooted cuttings of 15 clones were planted in one location near Indian Head, Saskatchewan. Once again, some of the clones in this study showed unusually poor performance, and so 6 of the 15 clones that were shorter than the average 15-year height were eliminated from the results.

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[6] DBH and percent survival was not evaluated in the 4-year age class.

Another complication is that not all of the stands were planted at the same density. An average stocking level of 1000 stems per hectare was used, since this was the target density for the 15 and 25-year studies.

It is important to note that the PFRA measurements were not obtained by following the same stand of trees through their life cycle, as would occur using permanent sample plots. Instead, the PFRA data are one-time measurements of a group of stands in the same age class. This means that the data for each age class is not gathered from the same trees, or even from the same sites. In using this data we are unable to isolate the effects of a number of potential explanatory variables, such as local site productivity and method of controlling competition, which could influence the yield curve. For all these reasons, we were unable to estimate yield curves for individual clones. Given the data that is available, we estimate a yield curve that may be considered to be an aggregate representation of hybrid poplar performance in western Canadian boreal regions.

Stem volume calculation

Before a growth curve could be estimated, the average volume for the 3 different age classes had to be calculated. To do this, the following hybrid poplar stem volume equation developed by the Ontario Ministry of Natural Resources (OMNR 1991) was used:

$$v(d,h) = \frac{1.013914e^{-2.884601+1.604938\ln(d)+1.203873\ln(h)}}{1000} \qquad [2.1]$$

where

$v =$ stem volume in cubic meters

$d =$ DBH in centimeters

$h =$ height of the tree in meters

This equation is based on 407 observations of hybrid poplar growing in eastern Ontario, and has an R^2 of 0.9877 and a root mean square of 0.0986 (OMNR 1991). Using this equation the stem volume was calculated for each clone measured in the PFRA studies. Since the DBH of the 4-year age class was not measured, an estimate of 3 cm was used based on the observation that hybrid poplars normally experience diameter growth of approximately 1 cm per year.[7] The low volume of the trees at this age makes this assumption of little importance to estimating the stand yield curve.

Stand volume calculation

The average stem density of the PFRA trials was approximately 1 000 stems per hectare. Since the percent survival in the 4-year age class was not measured, it was assumed to be

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[7] Barb Thomas, Adjunct Professor, Department of Renewable Resources, University of Alberta, personal communication, 6 May 2004

100%. Once again, the low volume of the stand at this age makes this assumption of little importance. Survival rates were measured for the other two age classes. By multiplying the individual clone's survival rate (which for all clones averaged 86% and 77% for the 15 and 25-year age classes, respectively) by the initial density of 1 000 stems per hectare, the number of surviving stems per hectare could be calculated for each clone. Then, multiplying this value by the value for stem volume obtained from Equation 2.1 gives the stand volume in cubic meters per hectare for that particular clone. To come up with a single stand volume for each of the three age classes, the stand volume values for each clone were averaged for the particular age class. The dataset is listed in Table 2.1.

Yield curve estimation

The average values from the three different sampling years were then used to derive a mathematical function that estimates the volume of a stand of hybrid poplar as it ages. Three different functional forms were analyzed: *(i)* the Chapman-Richards growth function, *(ii)* the Lundkvist-Korf growth function, and (iii) the McDill-Amateis growth function. To attempt to find the best functional form, the solver within Microsoft Excel was used to estimate the unknown parameters that minimize the sum of the absolute variations between the estimated yield and the empirical observation at the 3 age classes. The results of these optimizations are listed in Table 2.2, which suggests that the Lundkvist-Korf growth function provides estimates closest to the empirical data. Therefore the final form of the growth function used in this chapter for the remaining analysis is:

$$v(t) = 275e^{-\left(\frac{49.7}{t^{1.5}}\right)} \qquad [2.2]$$

Table 2.1. Complete data set.

Age Class	Clone	Avg. Ht. (m)	Avg. DBH (cm)	Est. Stem Vol. (m^3)	Percent Survival[~]	Stand Vol.[*] (m^3/ha)
4-year	Walker	4.6	3	0.002	100%	2.07
	Walker	4.4	3	0.002	100%	1.97
	Walker	4.3	3	0.002	100%	1.91
	Assiniboine	3.8	3	0.002	100%	1.65
	Assiniboine	3.3	3	0.001	100%	1.39
	Assiniboine	3.0	3	0.001	100%	1.24
Average		3.9	3.0	0.002	100%	1.71
Std. Dev.		0.6	0.0	0.000	0.0	0.34
95% C.I.						±0.35
15-year	Walker	12.6	18.2	0.126	83%	104.56
	Assiniboine	12.7	16.8	0.112	89%	99.54
	Manitou	13.2	21.2	0.170	100%	170.20
	Northwest	12.1	19	0.129	79%	101.56
	38P38	12.7	23.3	0.189	94%	177.71
	Plains Cott. ATNHC	11.2	20.1	0.128	89%	114.10
	Brooks #6	11.7	21.9	0.155	78%	120.95
	71-146	9.3	13.4	0.053	67%	35.82
	71-71	10.1	12.6	0.053	89%	47.61
	Griffin	10	15.3	0.072	61%	44.03
	Walker	16.9	21.2	0.229	100%	229.16
	Assiniboine	15.6	19.3	0.179	100%	179.00
	Northwest	14.3	20.2	0.173	100%	173.43
	38P38	15.6	25.6	0.282	94%	264.77
	Plains Cott. ATNHC	13.7	18.9	0.148	94%	139.15
	Brooks #6	13.7	17.1	0.126	89%	112.20
	71-146	10.1	13.7	0.061	89%	54.46
	71-71	12.2	13	0.071	100%	70.61
	71-172	14.3	19.1	0.159	78%	123.65
	Walker	15.1	19.4	0.174	89%	154.46
	Assiniboine	15.4	17.9	0.156	67%	104.64
	Manitou	12.4	18.1	0.122	72%	88.19
	Northwest	12.5	17.1	0.113	83%	93.70
	Plains Cott. ATNHC	11.5	18.1	0.112	79%	88.37
	Brooks #6	11.2	17.1	0.099	83%	82.10
	71-71	11.6	14.2	0.077	78%	59.72
Average		12.76	18.15	0.13	86%	116.68
Std. Dev.		1.96	3.20	0.05	0.11	56.67
95% C.I.						±22.89
25-year	Hill	15.1	25.6	0.271	100%	270.84
	Walker	13.3	20.8	0.167	86%	142.76
	Northwest	13.6	26.1	0.246	79%	193.60
	P. deltoides 709	15.3	28.2	0.321	64%	206.64
	P.x *berolinensis*	13	20.7	0.161	43%	68.99
	Tristis #1	13	20.2	0.155	71%	110.40
	Brooks #4	14.6	27	0.283	86%	242.77
	Grandifolia	14.9	26.1	0.275	93%	255.41
	nigra viadri	16.1	23.7	0.259	71%	184.58
Average		14.32	24.27	0.24	77%	186.22
Std. Dev.		1.13	3.02	0.06	0.17	68.01
95% C.I.						±52.28

[*] for some trials we were unable to locate the plot sizes in the PFRA literature

[~] percent survival for the 4-year age class assumed to be 100%

Table 2.2. Optimization results for the different growth functions.

CHAPMAN-RICHARDS				LUNDKVIST-KORF				McDILL-AMATEIS			
$v(t)=A(1-e^{-bt})^c$				$v(t)=Ae^{-(k/t^n)}$				$v_2 = A/[1-(1-(A/v_1))*(t_1/t_2)^a]$			
$A=$	275			$A=$	275			$A=$	275		
$b=$	0.1			$k=$	49.7			$a=$	3.6		
$c=$	1.9			$n=$	1.5						
Age Class	Empirical Vol (m^3/ha)	Estimated Vol (m^3/ha)	Absolute Variation	Age Class	Empirical Vol (m^3/ha)	Estimated Vol (m^3/ha)	Absolute Variation	Age Class	Empirical Vol (m^3/ha)	Estimated Vol (m^3/ha)	Absolute Variation
4	1.7	17.3	15.6	4	1.7	0.5	1.2	4	1.7	0.0	1.7
15	116.7	116.0	0.7	15	116.7	116.7	0.0	15	116.7	116.7	0.0
25	186.2	186.2	0.0	25	186.2	184.6	1.6	25	186.2	226.4	40.2
		min Total	16.3			min Total	2.8			min Total	41.9

For a visual representation of how well this function "fits" the average stand volumes measured for the three age classes, the curve for this function is graphed in Figure 2.1 on top of the 3 empirical data points and their respective 95% confidence intervals. As can be seen, the yield curve very closely estimates all three empirical data points. Dashed lines indicate how the growth function might intersect the upper and lower 95% confidence intervals. Values from these upper and lower growth functions will be used in the Results section to provide bounds for conducting sensitivity analysis.

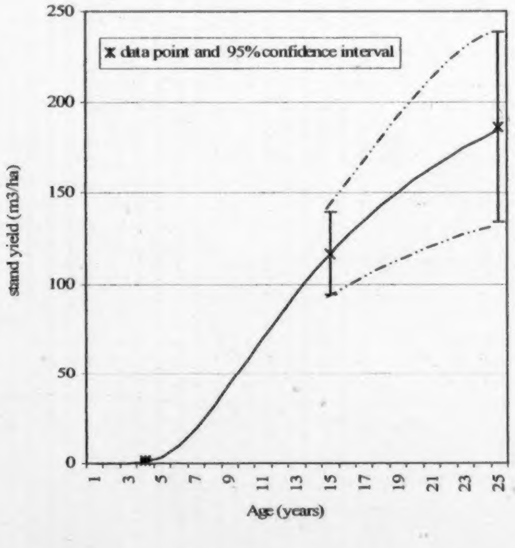

Figure 2.1. Estimated yield curve versus actual data points.

Figure 2.2 shows the average growth, represented by the mean annual increment (MAI), and the marginal growth, represented by current annual increment (CAI). The two curves intersect at the sustained yield rotation age of 19 years, which is the point where MAI is maximized.[8]

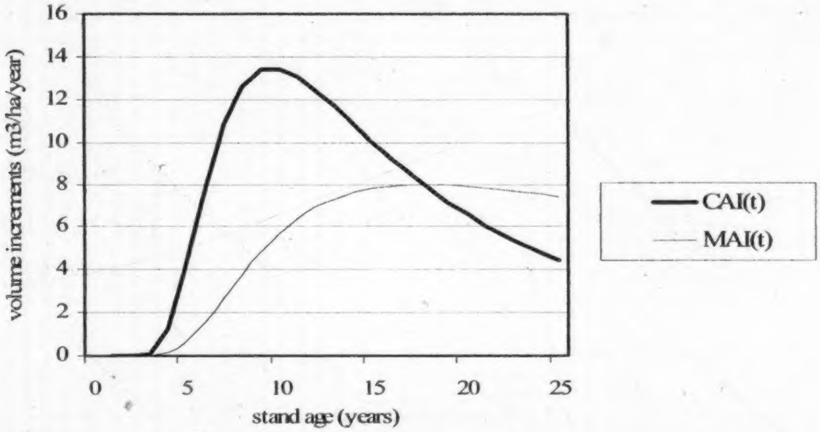

Figure 2.2. Current annual increment (CAI) and mean annual increment (MAI) at different stand ages.

Stand-Level Optimal Economic Rotation Model

General model assumptions

Timber used for producing pulp and strand-board is not normally valued on wood size. Accordingly, we assume that the real stumpage values per cubic meter of merchantable timber remain constant as trees grow.

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[8] As will be shown in the Results section, hybrid poplar under the base case assumptions has an optimal economic rotation (OER) of 19 years, which is the same as the sustained yield rotation (as shown by the point of intersection between the MAI and CAI functions in Figure 2.2). This is unusual for the boreal forest, where the long periods required for native species to grow typically leads to OERs being shorter than maximum MAI-based rotations.

When determining merchantable volume, three factors should be considered: *(i)* bark thickness, *(ii)* stump height, and *(iii)* the non-merchantable tree top. Bark thickness of short-rotation poplar has been found to be negligible (Benbrahim and Gavaland 2003). We also assume that the cultivated soil in plantations allow harvesting equipment to harvest the stumps at ground level, making wastage from stumps also negligible. In determining the wastage from the non-merchantable tree top, a merchantable top diameter of 7 cm is assumed. To estimate the length of each non-merchantable top, we use the ratio of average basal diameter to average height[9] for the 15 and 25-year age classes, which is 1.7 cm/m. Dividing the top diameter of 7 cm by this ratio gives an estimated top length of 4.1 m. Since it can be assumed that stems are conical close to the top (Kozak 1988, Saint André *et al.* 1998), inserting the top diameter and length into the volume equation for a cone, $v = 1/3\pi r^2 h$, reveals an estimated non-merchantable top volume of 0.005 m^3/tree.

It is assumed that this wastage is equal for all trees, regardless of age. Multiplying this value by the stand density equals the total wastage per hectare, which when deducted from the yield curve gives the net stand volume. The following financial analysis is based on net stand volume.

Model setup

The optimal economic rotation (OER) is the stand age where the marginal return from allowing the stand to grow another year equals the opportunity cost of the capital that would be generated from harvesting the current crop and regenerating the site, thereby maximizing the value of the forest land (e.g., Pearse 1990). This chapter uses a continuous-time version of the Faustmann formula, which determines the stand age, *t*, which is the OER for maximizing the SEV of an infinite stream of forest rotations. The equation is structured as follows:

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[9] The average total height is reduced by 1.3m (breast height) to estimate the height as it would relate to the *basal* diameter.

$$\max_t SEV = \frac{Pv_n(t) - Ce^{rt}}{e^{rt} - 1} \qquad [2.3]$$

where

$$C = \sum_{t=o}^{T} S_t e^{-rt} \qquad [2.4]$$

$P =$ the real net stumpage value per m^3 of timber (i.e. gate price minus harvest and haul costs)

$v_n(t) =$ the net stand volume (m^3) per hectare as a function of age

$r =$ the real interest rate

$S_t =$ the real silviculture cost per hectare incurred at time *t*

$T =$ that value of *t* that maximizes the value of SEV (i.e., the optimal economic rotation)

SEV represents the value of the land *to the landowner* when the land is used for growing hybrid poplar. As such, it can be compared to agricultural values of land to see how competitive hybrid poplar may be. But since many of the forestry firms currently contemplating hybrid poplar are foreign owned and cannot purchase land, the model must consider that firms make silvicultural investments without being landowners. Therefore the model has been restructured such that firms may choose to rent the required land at a fixed annual cost. In this case, the landowner does not realize the returns from selling the hybrid poplar, as is implicit in SEV. Instead, the landowner contractually agrees to a real annual land rent that remains constant throughout the rotation period. This annual land rent may be considered analogous to the timber dues that the government charges to forestry firms for timber harvested from public land. Yet such payments differ from current stumpage systems, where firms pay volume-based "stock rents" for harvesting existing mature timber, in that the tenants now pay area-based "land productivity rents" for the value of the land in its ability to produce future timber (Luckert and Bernard 1993).

In order to assess the financial viability *to the forestry firm*, we must calculate the value that considers rental payments to the landowner. To do this we add rental costs to Equation 2.4 to get:

$$C = \sum_{t=0}^{T} S_t e^{-rt} + \sum_{t=0}^{T} R_t e^{-rt} \qquad [2.5]$$

where

$R_t =$ the real land rent per hectare paid by the forestry firm to the landowner at time t.

Substituting Equation 2.5 into 2.3 we get:

$$\max_t NPVR = \frac{Pv_n(t) - \left(\sum_{t=0}^{T} S_t e^{-rt} + \sum_{t=0}^{T} R_t e^{-rt} \right) e^{rt}}{e^{rt} - 1} \qquad [2.6]$$

This maximized value represents the land value to a land-renting forestry firm. Since it is different than the original SEV in Equation 2.3, we define this new land value as the net present value to the land renter (NPVR). The fact that the forestry firm does not own the land may make infinite-period discounting seem counter-intuitive. But firms conduct plantation forestry to provide long-term timber supply, and are therefore likely to consider multiple rotations, even if operating on leased land. Hence, we treat the decision of whether or not to conduct plantation forestry as a long-term decision that warrants infinite-period discounting.

In addition to expressing the financial viability as both an SEV and an NPVR, we also provide additional financial information by calculating the internal rate of return (IRR) and the benefit-cost ratio (B/C) based on the NPVR values. Here, the IRR is defined as the interest rate such that the NPVR is equal to zero. It can be interpreted as the percentage rate that a silvicultural investment grows to produce future benefits (Pearse 1990). The real IRR is calculated from the above model finding the *r* that makes NPVR = 0. The B/C is the ratio of the present value of the timber to the present value of the total costs (including rent paid to the landowner). It can be interpreted as the benefits generated per dollar invested (Pearse 1990).

To account for the large number of exogenous variables in the model, a base case was developed using variables applicable to a typical pulp mill in Alberta. Then, to conduct sensitivity analysis, ten additional scenarios were chosen in which all of the variables in the base case were held constant except one—i.e., in each scenario we isolate one variable from the base case assumptions and assess the sensitivity of the IRR to a change in this variable. For these ten scenarios to be defined, we must first assume base case values for each exogenous variable. This base case represents our best estimate regarding the current values of the variables in the model. We then estimate a change for each exogenous variable upon which we wish to conduct sensitivity analysis.

Base case and sensitivity analysis assumptions

Calculating values with Equation 2.6 requires values for the following variables:

1. Net stumpage value (*P*)

This value represents the timber price received at the gate by the land-renting forestry firm minus all costs associated with harvesting and hauling the timber to the mill. The average non-conifer pulpwood value for Alberta in the third quarter of the year 2000 was \$45.88/m^3 (WRI 2000). After adjusting for the 2% average annual core inflation that occurred between 2000 and 2004 (Bank of Canada 2004), the 2004 *gate price* would be \$48.69/m^3. Harvesting is assumed to cost \$15/m^3 and load and haul are assumed to cost \$5/m^3 (approximately a 2 hour cycle time).[10] Deducting these harvest and haul costs yields *a net stumpage value (P)* of \$28.69/m^3.

While the average fibre cost for northern bleached softwood kraft pulp[11] between 1990 and 2003 was approximately US\$220 per tonne of pulp, the high was approximately US\$280 and the low US\$170 (WRI 2003); a range of almost 25%. Thus the historical volatility of pulpwood fibre costs suggests 25% as an appropriate factor for conducting sensitivity analysis.

2. Land rent (*R*)

Alberta-Pacific Forest Industries Inc. (Al-Pac) is currently entering into agreements with local landowners to rent land for \$62/ha/year (Thomas and Kaiser 2003). These agreements are usually for land with lower productive qualities. In conducting sensitivity analysis, the land rent was increased and decreased by 25%.

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[10] Andrew Swan, Forest Operations Consultant, Edmonton, Alberta, personal communication, 17 August 2004.

[11] Long run hardwood fibre costs are not available.

3. Silviculture costs (*S*)

Al-Pac is one of the few boreal forestry firms establishing hybrid poplar plantations on an operational basis, and has found the following silvicultural cost assumptions to be valid (Thomas and Kaiser 2003):

• Year 0: site preparation and planting:	\$950/ha
• Year 1: cultivation and herbicide:	\$77/ha
• Year 2: cultivation and herbicide:	\$77/ha
• Year 3: cultivation and herbicide:	\$77/ha
• Year 4: cultivation and herbicide:	\$77/ha

When all costs are discounted to year 0 and summed, the total present value (PV) of silviculture costs over one rotation is \$1231/ha. In conducting sensitivity analysis, the silviculture cost was increased and decreased by 25%.

4. Real interest rate (*r*)

In choosing the appropriate interest rate for private long-term forestry applications,[12] it is important to consider the opportunity cost of not investing in alternative investments. Since timberland investments are believed to have a risk level similar to corporate bonds, a potential benchmark is the Aaa corporate bond yields in the United States, which between 1970 and 1999 yielded an average nominal interest rate of 9.1% in the wake of average inflation of 5.2% (Buongiorno and Gilless 2003). Since real dollars are used exclusively in this model, the real rate of return must be used as a discount rate. The real rate of return is calculated using the formula $1+r = (1+R)/(1+\pi)$, where r is the real rate of return, R is the nominal rate, and π is the inflation rate. In this case, the real rate of return is 3.7%. In conducting sensitivity analysis, the real interest rate was increased and decreased by 1.5 percentage points.

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[12] There are conflicting views on what interest rate should be used for analyzing silvicultural investments. While this study uses a standard benchmark for private investors, there are arguments that favour a lower "social" interest rate (e.g., Harou 1985).

5. Stand yield parameters (*A, k* and *n*)

The base case uses the estimation from Table 2.2, which for the Lundkvist-Korf functional form derived the parameters A=275, k=49.7 and n=1.5. There is, however, current research using selective breeding and transgenic technologies to further increase growth rates by incorporating insect-, disease-, and herbicide-resistance (Pullman *et al.* 1998). When using the yield function estimated in this chapter, another important factor to consider is the degree of variability in the measurements between clones, as well as the large 95% confidence intervals resulting from this variation. Recall from Figure 2.1 the dashed lines used to estimate yield functions that would intersect the upper and lower bounds of these confidence intervals. These functions were used to set the upper and lower bounds for the sensitivity analysis, which at year 20 are a 27% increase and a 24% decrease in stand volume, respectively.

Results

The results of the sensitivity analysis are summarized in Table 2.3. Recall that the SEV values indicate the value of bare agricultural land for use in growing hybrid poplar, and may be compared with current agricultural land values to assess how competitive hybrid poplar may be. The NPVR values are based on leasing land for hybrid poplar production given current agricultural rental values. Any project with a positive NPVR is financially viable to the firm, assuming the required capital is available at the assumed discount rate.

The IRR and B/C values are calculated based on this leasing situation. The OER values indicate that rotation age which maximizes the SEV and NPVR values. Table 2.3 shows that these rotation ages do not vary much—ranging from18 to 24 years. Yet the financial measures change significantly, depending on the assumptions being made, as discussed below.

Table 2.3. Sensitivity analysis.[*]

Scenarios	SEV ($/ha)	NPVR ($/ha)	Benefit/Cost Ratio	Real IRR (%)	OER (years)
Base case	1 681	-87	0.98	3.6	19
1	2 733	961	1.22	5.1	18
2	664	-1 100	0.73	1.7	20
3	n/a	-529	0.89	2.9	19
4	n/a	355	1.09	4.3	19
5	1 080	-683	0.85	2.8	20
6	2 314	542	1.15	4.7	18
7	564	-700	0.79	n/a	18
8	4 490	1 529	1.24	n/a	20
9	3 698	1 890	1.38	6.7	13
10	768	-998	0.74	2.1	24

Specifications:
Base case:
a. Net stumpage value = \$28.69/m^3 (WRI 2000)
b. Total Present Value of Silviculture costs = \$1 231/ha (Thomas and Kaiser 2003)
c. Land rent = \$62/ha (Thomas and Kaiser 2003)
d. Real interest rate = 3.7% (Buongiorno and Gilless 2003)
e. Yield parameters: A = 275, n = 1.5 and k = 49.7
NOTE: real IRR is solved for NPVR = 0 with all other variables held constant

Alternative scenarios:
Scenario 1: Base case except 25% increase in net stumpage value (from \$28.69/m^3 to \$35.86/m^3)
Scenario 2: Base case except 25% decrease in net stumpage value (from \$28.69/m^3 to \$21.52/m^3)
Scenario 3: Base case except 25% increase in land rent (from \$62/ha to \$77.50/ha)
Scenario 4: Base case except 25% decrease in land rent (from \$62/ha to \$46.50/ha)
Scenario 5: Base case except 25% increase in total present value of silviculture costs (from \$1,231/ha to \$1,539/ha)
Scenario 6: Base case except 25% decrease in total present value of silviculture costs (from \$1,231/ha to \$923/ha)
Scenario 7: Base case except 1.5 percentage point increase in real interest rate (from 3.7% to 5.2%)
Scenario 8: Base case except 1.5 percentage point decrease in real interest rate (from 3.7% to 2.2%)
Scenario 9: Base case except 27% increase in gross stand volume at year 20 (from 158m^3/ha to 200m^3/ha)
Scenario 10: Base case except 24% decrease in gross stand volume at year 20 (from 158m^3/ha to 120m^3/ha)

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[*] Abbreviations are as follows: SEV is soil expectation value, NPVR is net present value to the land renter, IRR is internal rate of return, and OER is optimal economic rotation.

Base case

The base case SEV suggests that the value of bare agricultural land for use in growing hybrid poplar is approximately $1 681 per hectare. In contrast, when considering the leasing costs to the firm, the NPVR drops to -$87 per hectare. This result suggests that the leasing costs of agricultural land are such that this land is worth slightly more than the $1 681 per hectare land value based on using the land for hybrid poplar. However, if we were to use a discount rate of 3.6% instead of the 3.7% value assumed in the SEV and NPVR calculations, then the NPVR would be zero, indicating 3.6% is the IRR for the investment, and the B/C ratio would be 1. This situation would represent the break even point for the investments. Higher returns would be indicated by a higher IRR, a positive NPVR and a B/C ratio greater than one. Because of the interrelationships among the financial measures in Table 2.3, in the discussion that follows, we largely concentrate on describing the IRRs.[13]

Scenarios 1 and 2: *Changing the net stumpage value*

Scenario 1 in Table 2.3 shows that a 25% increase in net stumpage value raises the real IRR to 5.1% from its base case value of 3.6%. Scenario 2, however, shows that a 25% decrease in net stumpage price decreases the real IRR to 1.7%. This variable shows a high degree of sensitivity.

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[13] For scenarios 8 and 9 we describe NPVRs instead or IRRs. This is done because we are investigating impacts of changing the discount rate instead of solving for the discount rate as is done with IRRs.

Scenarios 3 and 4: ***Changing the land rent***

Scenario 3 in Table 2.3 shows that a 25% increase in land rent decreases the real IRR to 2.9% from its base case value of 3.6%. Scenario 4, however, shows that a 25% decrease in land rent increases the real IRR to 4.3%. This relationship is shown in Figure 2.3. Using policy to exploit the sensitivity of returns to land rents will be discussed later in this chapter.

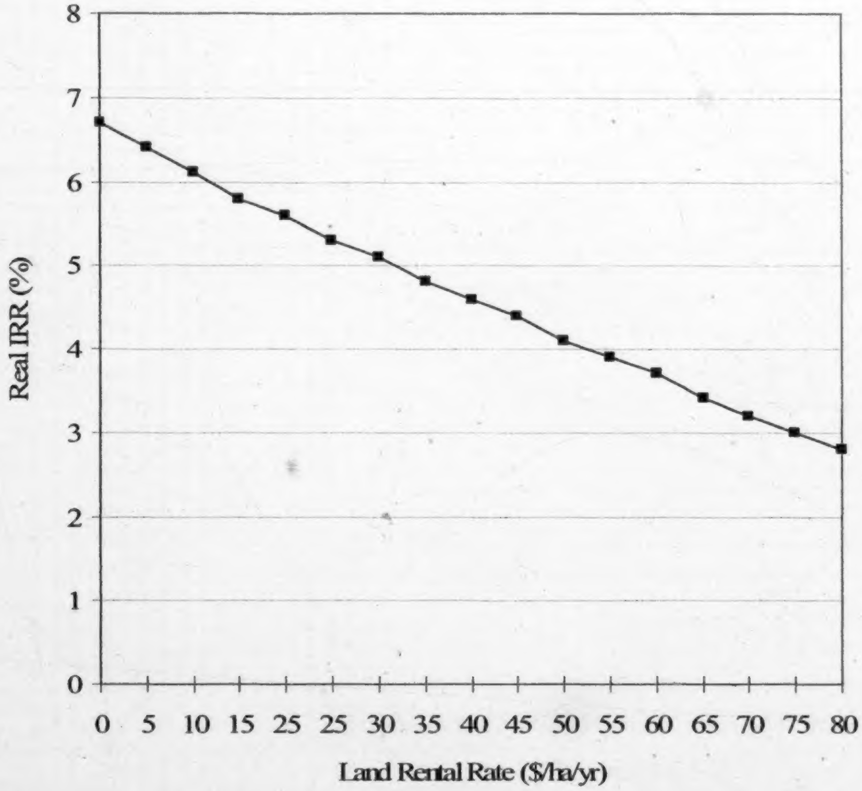

Figure 2.3. Real internal rate of return (IRR) for base case scenario with different land rents.

Scenarios 5 and 6: ***Changing the total present value of silviculture costs***

Scenario 5 in Table 2.3 shows that a 25% increase in total present value of silviculture costs decreases the real IRR to 2.8% from its base case value of 3.6%. Scenario 6, however, shows that a 25% decrease in total present value of silviculture costs increases the real IRR to 4.7%. This relationship is shown in Figure 2.4.

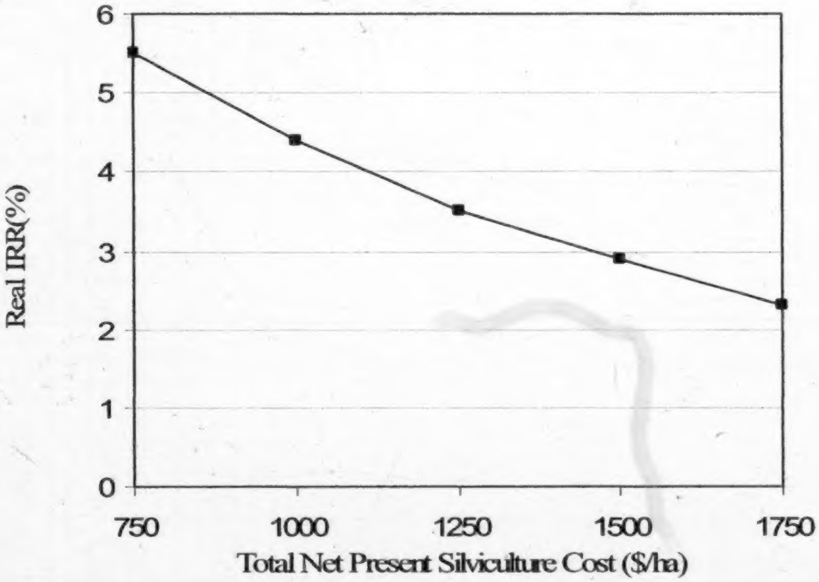

Figure 2.4. Real internal rate of return (IRR) for base case scenario with different silviculture costs.

Establishing short rotation plantations is relatively new in Canadian boreal regions. This inexperience suggests the potential for increased efficiency as firms develop innovative new plantation systems applicable to local conditions. One potential cost saving relates to planting stock. The cost examples used in the base case are for planting rooted cuttings that have spent time developing roots in a greenhouse. In many areas, such as the Pacific Northwest, un-rooted poplar whips are planted successfully. This eliminates the greenhouse time required to root the cuttings, and also eases seedling storage, transportation, handling and planting—reducing the cost of all these activities. More research is needed, however, to determine if this technique will be successful in western Canadian boreal regions.

Scenarios 7 and 8: *Changing the real interest rate*

Scenario 7 in Table 2.3 shows that a 1.5 percentage point increase in real interest rate decreases the NPVR to -$700 per hectare from its base case value of -$87 per hectare. Scenario 8, however, shows that a 1.5 percentage point decrease in real interest rate increases the NPVR to $1,529 per hectare.

Since the costs and benefits of plantation forestry occur at different times, interest rates, which measures how much more private firms value having money now versus having money in the future, have a significant impact on the financial viability of intensive forest management.

Scenarios 9 and 10: *Changing the growth rate*

Scenario 9 in Table 2.3 shows that a 27% increase in stand volume at year 20 increases the real IRR to 5.1% from its base case value of 3.6%. Scenario 10, however, shows that a 24% decrease in stand volume at year 20 decreases the real IRR to 2.1%.

A relatively small increase in growth rate may be all that is necessary to make intensive forestry financially favorable on private land in Alberta. Given the diversifying effect poplar domestication could have on the Canadian forest industry, it might deserve to be a higher research priority. Opportunities to increase the level of research on hybrid poplar growth will be discussed later in this chapter.

Policy considerations

A number of policy considerations could influence the sensitivity analysis presented above. Below we consider: *i)* attempting to increase growth rates through increased research and innovation, *ii)* non-timber aspects of hybrid poplar plantations, *iii)* allowing hybrid poplar plantations on public land, and *iv)* allowing plantations on private land to be combined with forest management agreements on public land.

Increasing growth rates

There is currently a large knowledge gap regarding the growth potential of hybrid poplar in Canada's boreal forest. There may be the opportunity to increase stand yield by increasing the planting density. Pulpwood hybrid poplar plantations in France planted at densities of 1 900 stems per hectare produced stand growth rates almost double those estimated in this study (Benbrahim and Gavaland 2003). There is also speculation that boreal regions are nutrient limited and may need fertilization to achieve higher growth rates (Weih 2004).

Further site specific optimization of growing stock also seems likely. The base case yield curve estimate uses almost all of the available data, and thus represents a *low risk* aggregate yield curve for western Canadian boreal regions. It is important to understand, however, that the PFRA studies are essentially breeding trials. Many of the poor performing clones used in this chapter for the base case yield curve estimation would likely be eliminated from further breeding or commercialization. Eliminating these clones has a significant impact on the yield curve. In the 15-year age class, only the 8 poorest performing clones out of the total of 26 (31%) need to be eliminated for the growth curve to reach the upper bound of the 95% confidence interval, while the 25-year age class requires the elimination of 5 out of the 9 (56%) clones. This suggests that the upper bound yield curve modeled in scenario 9, with its MAI of approximately 10 m^3/ha/year and real IRR of 5.1%, might be more probable.

Barb Thomas believes that simply selecting clones for western Canadian conditions, combined with appropriate silvicultural techniques, will achieve growth rates similar to scenario 9, and that once this is completed, further improvements to these clones could eventually push the upper bound MAI to approximately 12 m^3/ha/year.[14] This MAI represents a real IRR of approximately 6.2%. But the size and heterogeneity of the western Canadian boreal region suggests that different clones might perform better in different regions, and achieving this performance over such a large area will likely require localized research and testing.

Another consideration is that the scope of this chapter has been limited to considering traditionally bred or selected hybrid poplars. Yet scientists have recently released the genome sequence for *Populus*, which represents the first sequence for a tree. By using biotechnology to build on this knowledge, tree breeders may be in a position to rapidly increase growth rates and decrease susceptibility to volume losses through gene selection and marker aided selection of specific traits and or processes (Tuskan *et al.*

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[14] Barb Thomas, Adjunct Professor, Department of Renewable Resources, University of Alberta, personal communication, 1 October 2004

2003). But other forest regions and species will also likely gain from such technological advances, thereby raising the bar necessary for Canada to compete internationally. It remains to be seen which region will gain more than others from these new technologies.

Despite the potential for such advances in Canada, it is possible that more research in hybrid poplar has not been conducted because policy constraints in Canada may be diminishing the benefits of increased knowledge (Nilsson *et al.* 2004). To remedy this, the government could make strategic policy changes that might provide industry with enough incentive to fund additional research. If a policy framework is in place such that firms can capitalize on information about improving growth rates, then more research will be conducted. Such potential policy changes are discussed below.

Non-timber values

The above calculations are based solely on the fibre values of forests. Yet there are a number of other considerations that could favour or impede the expansion of hybrid poplar plantations in Canada's boreal forest. With Canada's focus on curbing greenhouse gas emissions, carbon values could enter into the financial viability of establishing plantations (e.g., van Kooten *et al.* 1999). In 2005, European Union emission permits were trading for \$26.85/tonne of carbon dioxide (Point Carbon 2005). With one m^3 of hybrid poplar being approximately equal to 0.2 tonnes of carbon, these permits would increase our base case net stumpage value estimate to \$34.06/m^3, which would increase the real IRR from 3.6% to 4.7%. This finding, however, assumes zero decomposition of the harvested forest product, and is therefore likely to be optimistic (e.g., van Kooten *et al.* 1995). Decomposition of forest products makes carbon withdrawal temporary; and temporary carbon withdrawals are less valuable than permanent withdrawals. Nonetheless, our finding is supported by a recent study which considered the temporary nature of forest product decomposition, and found that for an MAI of $10m^3$/ha/year and a carbon dioxide price of $25/tonne, the apparent land availability for poplar plantations would be 310 000 hectares in Western Canada and 20 000 hectares in Eastern Canada (McKenney *et al.* 2004). But Canada is no longer committed to the Kyoto Protocol, and therefore European carbon prices may not be relevant. Should Canadian firms chose voluntary emissions trading, they might purchase offsets on the Chicago Climate Exchange, which in 2008 cost only $6/tonne (CCE 2008). Such low carbon prices could nullify the potential for carbon to improve the financial viability of poplar plantations in boreal regions.

Moreover, poplar plantations could play an important role in fire and pest management. To the extent that deciduous species are more fire resistant than coniferous (Cumming 2001), as well as being resistant to the mountain pine beetle (NRC 2005), there may be an added value to integrating them into forest level management plans.

Finally, there may be non-timber aspects of poplar plantations that decrease their value to society. Some groups may be opposed to establishing such plantations, especially if they are based on genetic engineering rather than just traditional cross-breeding. The land-use prior to the establishment of plantations may also play an important role in their acceptability. If indigenous forest land is replaced with exotic plantations, then the loss of biodiversity could be of concern. Such concerns may be alleviated if plantations are established on previous agricultural lands, or if other more sensitive areas of land are protected as a trade-off.

Allowing hybrid poplar on public land: The crown white area in Alberta

Recall that current provincial legislation prohibits foreign firms from purchasing private land in Alberta. But instead of renting private agricultural land, there is also the potential for firms to rent public agricultural land. Alberta's Crown white area is the band of public land that runs along the transition zone between agriculture and the boreal forest. Over 2.4 million hectares of this land is currently managed for agriculture as cattle grazing pasture (SRD 2003). It is likely that much of this pasture is able to sustain growth rates similar to the base case hybrid poplar MAI of 8 m^3/ha/year. One problem, however, is that these pastures would initially require more site preparation to remove large stumps and rocks than most private agricultural land would require. But since the current system for grazing leases only generates provincial revenues of approximately \$1.67/ha/year (SRD 2003), it is possible for hybrid poplar plantations to be financially viable even under higher site preparation costs.

For example, imagine pastureland in the crown white zone that is leased to a timber company for \$3.34/ha/year, which is double the return from grazing. A 1994 study found that in Alberta the average land clearing costs—after all merchantable timber had been harvested—were approximately \$300/ha (Westworth 1994). Then, modeling the base case with land rent of \$3.34/ha/year and an increase in year zero silviculture costs of \$300/ha, the resulting real IRR is 5.0%. Thus, this simple analysis suggests it could be possible for the government to set land rental rates for hybrid poplar higher than for grazing, while still ensuring hybrid poplar plantations are financially viable despite higher site preparation costs.

Combining private land plantations with public forest management agreements

The allowable cut effect (ACE) is an immediate increase in annual allowable cut (AAC) attributable to expected future increases in yield (Schweitzer *et al.* 1972). Regardless of whether plantations are established on private or public land, they increase expected future yield; and in settings where harvests are regulated by sustained yield, the ACE could be applied. For example, private land could be contractually combined with public land to activate the ACE, thus allowing a firm to increase its AAC in existing timber from public lands because of increased productivity shown in poplar stands.

For firms to pursue the ACE, the profits experienced from the increase in AAC must offset the costs in establishing the plantations. Yet these benefits to the ACE only arise because of the significant costs of the sustained yield constraint; and implementation of ACE policies may not be advisable because they may prolong the continuance of sustained yield policies (Luckert 2001). Although beyond the scope of this chapter, the ACE is another possibility for making hybrid poplar plantations financially viable in the boreal forest, and its advantages and disadvantages should be explored further.

Conclusions

Roger Sedjo (1999), director of the forest economics and policy program at Resources for the Future, has stated that:

> In recent years, there have been two impediments to plantations. The first relates to concerns over political stability and the unwillingness to make long-term financial commitments in an unstable political environment…The second

> impediment is found in the objections to plantations that are being made by some environmental groups. To overcome these objections it must be demonstrated that plantation forestry can serve a protective function for native forests, generate positive environmental benefits, and mitigate any associated environmental damages and social disruptions.

As a developed country, Canada is impacted little by the first impediment. This situation contrasts with many of the politically volatile subtropical countries where a large number of plantations are currently being established. The second impediment may not apply either, since under priority-use zoning there could be more land protected as ecological preserves. For such a change to occur, however, society would have to accept the environmental consequences of intensively managing exotic species—such as extensive herbicide use, decreased biodiversity, and increased water and nutrient usage—in exchange for increasing the amount of preservation.

Indeed, the scale of this exchange could be grand. Consider, for example, that some countries produce almost 100% of the wood fibre for pulp and paper from industrial plantations (Sedjo 1999). If this were the case in Canada, using the base case assumption that plantations grow 2.5 times faster than native forest, this would imply that the Canadian forest industry could protect approximately 60% of the current pulpwood and strand-board producing land base while maintaining current output of forest products.

There is currently some momentum within the government towards more serious consideration of plantations. In 1999, the Canadian Council of Forest Ministers launched the program Forests 2020, with the intent to "make better use of fast growing, high-yield plantations and intensive silviculture, along with existing forest management practices…to help Canada meet increasing global demand for wood products, while ensuring an acceptable level of forest ecosystem conservation and increased local benefits from all forest resources (CCFM 2001)." More recently, a new initiative of this programme is "…to demonstrate the value of fast-growing plantations across Canada and evaluate options that could attract investments in future Canadian plantations, by taking advantage of the combined benefits of both wood fibre and carbon values" (CCFM undated). But as this chapter has shown, only exotic species are likely to produce positive financial returns, yet information available to assess financial prospects of these species is scarce. Moreover, a number of policy considerations could currently be blocking a move towards plantation forestry.

Given these limitations, a priority-use zoning system might address the challenges facing Canada's forest industry. But this analysis suggests that within Alberta, intensive forestry using hybrid poplar is in a financial "grey area". Therefore policy changes, such as those listed above, may be required before the forest industry transitions towards a priority-use zoning system using exotic species in the intensive zones. This opinion is supported by a recent review paper in the Canadian Journal of Forest Research, which concluded that "the major barriers for a rapid development of short rotation forestry, especially in the major agricultural regions of the boreal zone, appear not to be climatic, technical, or environmental constraints, but rather sociopolitical issues (Weih 2004)."

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CHAPTER 3. FOREST-LEVEL ANALYSIS

Introduction

In a recent article, Christian Messier (2007) suggests using "one hectare of hybrid poplar ... to put aside 5 to 14 hectares of forest for other purposes." Although "other purposes" could include land-use by other industries, he stresses that it should also include additional preservation. In this case, preserves would be areas set aside for the protection and propagation of biodiversity. Messier is not the only scientist calling for more preservation. In a letter signed by some 1500 scientists from more than 50 countries, the boreal forest—or more specifically, its water, wildlife and carbon—is said to be at risk unless at least 50% is preserved (CBC 2007). Such large scale preservation could be destabilizing for forestry firms, which have made significant capital investments based on current levels of timber production. But plantations could offset preservation. In this chapter we explore the economic implications of using the increased productivity of fast-growing exotic plantations to maintain or increase current harvest levels while increasing preservation.

Increasing plantations to increase preservation also has the support of Stanford University's David Victor and The Rockefeller University's Jesse Ausubel (2000). They foresee a "Great Restoration" of natural forests because "efficient farmers and foresters are learning to spare forestland by growing more food and fiber in ever-smaller areas." In an article published in *Foreign Affairs*, the authors suggest that continuing this evolution towards plantations will shrink production forests to about 12% of woodlands by 2050. Providing a policy framework for plantations and preservation is one of the motivations behind priority-use zoning systems.

A priority-use zoning system proposes using highly productive intensive zones to maintain historical timber production while creating new preservation zones (Gladstone and Letig 1990, Hunter and Calhoun 1996, Binkley 1997). Zoning emphasizes land-use specialization, where intensive zones produce timber values and preservation zones produce non-timber values. It differs from Canada's current emphasis on multiple-use management, which arguably implies that a single hectare of land can be all things to all people. Instead, Vincent and Binkley (1993) suggest that if a forest is divided into identical stands, "optimal management will tend toward dominant use in each stand whenever one of the two products produced by the forest is more responsive to management effort than is the other." In other words, multiple-use management may inefficiently deploy management inputs in generating both timber and non-timber products. The land-use specialization imposed by priority-use zoning could be a solution to such inefficiencies.

Zoning could also make Canada's financially beleaguered forest industry more competitive by reducing the forestry footprint—the amount of land needed to produce enough timber to supply the mills. Transporting timber from the forest to the mill is expensive, so a firm's profitability is somewhat dependent on its log-haul distance. The increased productivity of exotic plantations reduces the size of the forestry footprint, thus potentially increasing profits.

The international trend of replacing timber harvested from natural forests with timber from fast-growing exotic plantations (Sedjo 1999) is arguably not occurring in Canada. Instead of having a low cost supply of exotic timber close to mill sites, much of Canada continues harvesting widely dispersed remnants of virgin timber. Hence, Canada's forestry sector faces upward pressures on costs at a time when globalization may exert downward pressures on commodity prices.

Priority-use zoning is a possible solution to this financial challenge as it could give incentives for Canadian firms to invest in plantation forestry. But plantation forestry is challenged by the fact that intensively managing native species in Canadian boreal regions are not generally financially feasible at the stand-level (Rodrigues *et al.* 1998). There are, however, alternatives to native species; and policy reform could make intensive management of exotic species feasible in Canada's boreal regions (Anderson and Luckert 2007).

Our objective is to assess if land-use specialization occurs in Canadian boreal regions when policy barriers are lifted. We begin by defining policies that could enable firms to implement priority-use zoning. Then we use a timber supply model to estimate how these policies influence the behaviour of a profit-maximizing forestry firm. Specifically, we are interested in how each policy impacts profits and the spatial composition of the forest, which includes the location of plantations and preserves.

We build upon articles by Montigny and MacLean (2006) and Krcmar *et al.* (2003). Both these articles use timber supply models to analyze triad, which is a particular priority-use zoning system that utilizes three zones—intensive, extensive, and preserved. And both find that higher environmental demands may be satisfied under the triad regime without increasing the financial burdens on the industry or reducing its wood supply.

Our approach differs from these articles in three major ways: First, instead of comparing one version of triad to the status-quo, we analyze how different policies enable firms to implement different forms of triad. Second, instead of studying solely private land (Montigny and MacLean 2006) or solely public land (Krcmar *et al.* 2003), we look at interactions between private and public land. Finally, instead of conducting a case study of a particular area—in these cases, New Brunswick (Montigny and MacLean 2006) and coastal British Columbia (Krcmar *et al.* 2003)—we construct a stylized deciduous forest management unit in Canadian boreal regions.

In the next section we describe the various policies to be analyzed. Then we describe the starting inventory and yield assumptions for the stylized forest. A simple linear programming based timber supply model is then developed. Finally, we show the modelling results for each of the policies, and conclude with a brief discussion.

Policy descriptions

For the remainder of this chapter we explore six policies that could give firms financial incentives to increase plantations and preservation.

Maximum sustained yield policy

The maximum sustained yield (MSY) policy is used as a baseline. The MSY policy does not involve zoning, but instead ensures public land is managed to maximize timber production using only native tree species. In addition, the MSY policy considers the financial costs and benefits of producing this harvest level. As the maximum productive potential of native tree species, this policy serves as a baseline for evaluating upcoming policies which use exotic tree species. For example, in the subsequent analysis firms are forced to produce the MSY harvest level, but are allowed to use private land exotic plantations in doing so.

Public-private zoning policy

The public-private zoning (PPZ) policy allows firms to maximize profits within a framework of combined public and private land to produce the harvest level calculated using the MSY policy. The PPZ policy assumes provincial governments utilize sustained yield policies and that governments will be satisfied if the MSY level of timber is produced, regardless of *how* it is produced. In other words, the PPZ policy forces a firm to produce as much timber as in the aforementioned MSY policy, but the timber can be produced using a combination of native species on public land and exotic species on private land.

Since part of the MSY harvest is now being produced on private land, it frees up some public land for preservation. And since the PPZ policy maintains the MSY level of harvest, there should be little (if any) impact on production levels from preserving the public land no longer needed for timber production.

In essence, the PPZ policy is relaxing the "use-it-or-lose-it" policies which are present for much of Canada's public forest. "Use-it-or-lose-it" policies are meant to maximize industrial development by forcing a firm to use all of its public forest for timber production, or risk losing it to another firm. These policies enable firms to reduce their harvest level over the short-term—e.g., during periods of poor market conditions—but provincial governments have the option of reallocating land not used for timber production over the long-term.

The PPZ policy acknowledges that transporting logs from the forest to the mill is expensive, and that a firm's profitability is dependent on its log-haul distance. So if it is profitable for a firm to use private land as a means of shrinking its forestry footprint, the PPZ policy allows it. But instead of losing the land no longer managed for timber production, the PPZ policy enables the firm to preserve it.

Policies allowing the combination of private and public land have already been implemented in some jurisdictions. For example, British Columbia allows private forestland to be managed in conjunction with public land managed under a Tree Farm License (Zhang 1996).

Private land allowable cut effect policy

The private land allowable cut effect (PLACE) policy is similar to the PPZ policy in that it also allows a combination of private and public land. The policies differ, however, in that the PLACE policy does not require the firm to maintain the MSY harvest level. In this case, the PLACE policy allows firms to exceed the MSY harvest level if it is profitable to do so, so long as a sustained yield of timber is maintained.

Sustained yield policies require firms to harvest a sustainable annual allowable cut (AAC) from most of Canada's public forest (CFS 2006). One means of increasing this AAC is through the allowable cut effect (ACE). The ACE allows for an immediate increase in AAC attributable to expected future increases in yield (Schweitzer *et al.* 1972). The PLACE policy allows private forest land to be combined with public forest regulated by sustained yield. Establishing these private land plantations increases the AAC for the entire area. The only different between the PLACE policy and the PPZ policy is that the AAC is no longer limited to MSY levels. The only constraint on AAC for the PLACE policy is that it be sustainable.

Maximum sustained yield - public land exotic policy

The maximum sustained yield - public land exotic (MSY-PLE) policy relaxes the restrictions banning exotic species from most of Canada's public land. Consider, for example, the more than 2.3 million hectares of public land that is leased for grazing in Alberta (SRD 2003). A stand level analysis suggests that if exotic plantations were charged the same land rental rate as these grazing leases, they would be financially feasible (Anderson and Luckert 2007).

Regulations banning exotics from much of Canada's public land (see Johnston *et al.* 2006) are meant to protect the natural gene pool of Canada's native trees by requiring tree seedlings be started from seeds gathered near where they will eventually be planted. Some fear that allowing foreign and hybrid species will not only dilute the gene pool, but will also open the door for genetically engineered trees, a controversial practice which Greenpeace (2007) calls "genetic pollution."

Although new to Canada, policies similar to the PLE policy occur elsewhere. For example, in New Zealand public land exotic plantations ease the pressure on native forests such that around 75% is preserved (MAF 2007a). Contrary to Canada, New Zealand regulates natural forests on private land more than exotic plantations on public land. Private land natural forests must be managed for sustained yield, whereas public land exotic plantations can be managed according to market conditions (MAF 2007b). These policies are opposite to Canada, where public land natural forests must be managed for sustained yield and private land exotic plantations are managed according to market conditions.

Similar to the MSY policy, the MSY-PLE policy does not encourage zoning, but instead ensures public land is managed to maximize timber production—this time using either native or exotic tree species. The MSY-PLE policy also considers the financial costs and benefits of producing this harvest level. As the maximum productive potential of public land, this policy serves as a baseline to evaluate upcoming policies which incorporate private land.

Public-private zoning – public land exotic policy

The public-private zoning – public land exotic (PPZ-PLE) policy allows firms to maximize profits by combining public and private land to produce the harvest level calculated using the MSY-PLE policy. This policy is identical to the PPZ policy, except exotic plantations can now be established on public land, and the baseline harvest level that must be achieved is now determined using the MSY-PLE policy, instead of the MSY policy.

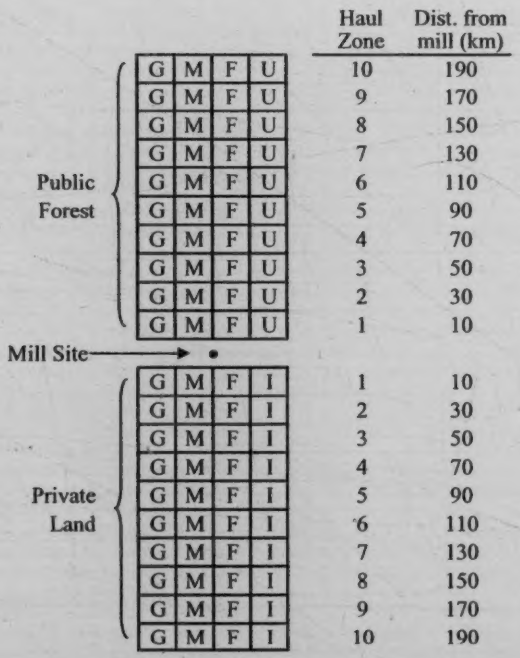
Private land allowable cut effect – public land exotic policy

The private land allowable cut effect – public land exotic (PLACE-PLE) policy allows the combination of private and public land, but does not require the firm to maintain any particular harvest level. In other words, the PLACE-PLE policy allows firms to harvest whatever level is most profitable, so long as a sustained yield of timber is maintained.

The difference between the PLACE-PLE policy and the PLACE policy is that exotic plantations can now be established on public land.

Data

To model conditions similar to deciduous forest management units within Canadian boreal regions, we construct a stylized representation of a mill site, as well as the surrounding public and private land. We assume the mill site can access two million hectares of land, of which half is public and half is private. The mill site is spatially located directly between the private and public land (see Figure 3.1).



					Haul Zone	Dist. from mill (km)
Public Forest	G	M	F	U	10	190
	G	M	F	U	9	170
	G	M	F	U	8	150
	G	M	F	U	7	130
	G	M	F	U	6	110
	G	M	F	U	5	90
	G	M	F	U	4	70
	G	M	F	U	3	50
	G	M	F	U	2	30
	G	M	F	U	1	10
Mill Site						
Private Land	G	M	F	I	1	10
	G	M	F	I	2	30
	G	M	F	I	3	50
	G	M	F	I	4	70
	G	M	F	I	5	90
	G	M	F	I	6	110
	G	M	F	I	7	130
	G	M	F	I	8	150
	G	M	F	I	9	170
	G	M	F	I	10	190

Figure 3.1. Visualized depiction of the stylized land base showing distance from the mill site and distribution of timber productivity ratings.*

* Each square represents 25 000 ha. Timber productivity ratings (TPRs) are abbreviated as follows: G is good, M is medium, F is fair, U is unproductive, and I is inaccessible.

The landscape is segmented into development types, each of which is described using the following five attributes:

(i) Land type. Each development type is either private or public.

(ii) Haul zone. Each development type is located in one of ten different haul zones. They range from 10 to 190 kilometers from the mill site.

(iii) Species/management. All private development types start as agriculture and all public development types start as native species growing along the LFN (leave for natural) yield curves (discussed in next paragraph). Each development type can be differentiated as LFN, native plantation, exotic plantation, agriculture, or preserve. For a description of possible modelling transitions for each species/management, see Figure 3.2.

From\To	LFN	Native plant	Exotic plant	Preservation
LFN	Y	Y	Y	Y
Native plant	Y	Y	Y	Y
Exotic plant	N	N	Y	N
Preservation	N	N	N	N

Figure 3.2. Possible modelling transitions for each species/management on public land.*

* Private land can only transition from agriculture to exotic plantation. Abbreviations are as follows: LFN is leave for natural, Y is yes, and N is no.

(iv) Timber productivity rating. There are four timber productivity ratings (TPRs): good, medium, fair, and unproductive/inaccessible. Within each haul zone, the TPRs are assigned such that 25% (i.e., 25 000 ha) of the land is in each TPR. For public land, the unproductive TPR represents land with poor soils incapable of producing merchantable timber. For private land, the inaccessible TPR represents land which the forestry firm is not able to access because of land ownership issues. There are yield curves for each species corresponding to the three productive TPRs, as shown in Figure 3.3. These yield curves are meant to be a representation of deciduous timber production typical to Canadian boreal conditions, as they roughly correspond to yield curves for native boreal species (e.g., see AFS 1985), as well as to yield curves for hybrid poplar as compiled by Anderson and Luckert (2007).

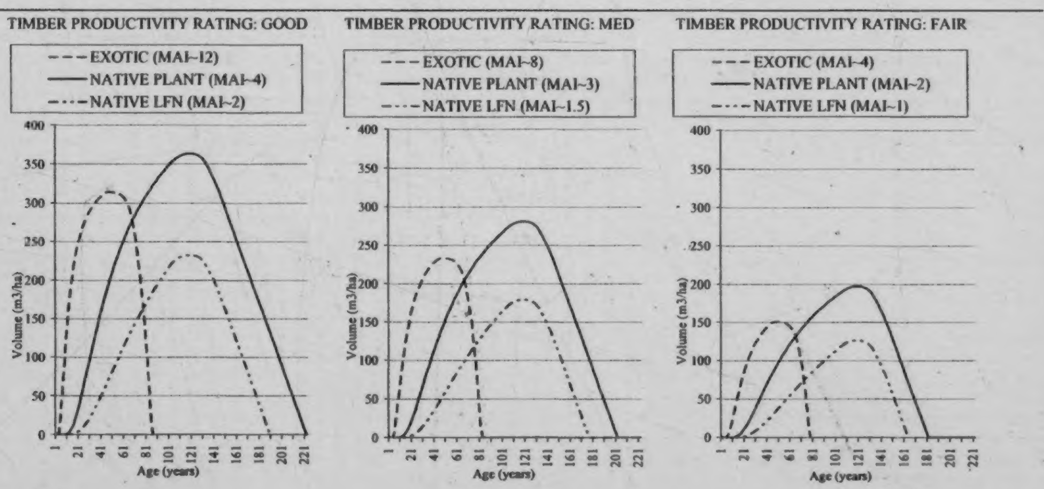


Figure 3.3. Yield curves by timber productivity rating and species/management.*

* Abbreviations are as follows: LFN is leave for natural and MAI is mean annual increment, which has units of m^3/ha/yr.

(v) Age. If a development type is forested, it is assigned to a 5-year wide age class. The public forest's starting age distribution is assumed to be comprised of young and old timber, with a gap in the middle (see Figure 3.4). Such an age class distribution is representative of much of Canada's forests (NRC 2007), which in many regions has experienced little harvesting, and therefore is still predominantly virgin timber.

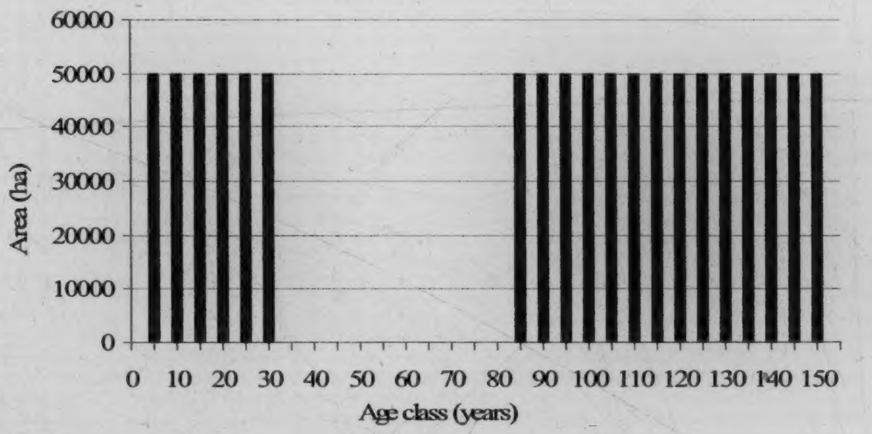


Figure 3.4. Initial age class distribution of public forest.

Timber supply model

We use a linear programming based spatial timber supply model to evaluate policies with respect to two model outputs: *(i)* the financial value of timber production and *(ii)* the spatial allocation of private and public land to the different land-uses. Recall that the landscape is segmented into development types, and each development type is described using the five landscape attributes. However, a development type is not a discrete unit, and the model need not allocate the entire development type to a particular land-use. Consider, for example, a 1000 hectare development type with the following landscape attributes: public land, haul zone 8, LFN, medium TPR, and stand age of 100-years. When determining the optimal land-use allocation for this particular development type, the model has the option of splitting it up. Indeed, it is possible that the model harvests 300 hectares per period in periods 1, 2 and 3, in which case it could allocate the first 300 hectares to LFN, allocate the other 600 hectares to native plantations, and finally, allocate the remaining 100 hectares to preservation.

When determining the optimal allocation, our model maximizes the net present value of timber production to a forestry firm, while satisfying the constraints imposed by the aforementioned policies. The model was constructed using the Woodstock forest management system (Remsoft 2004). Input files can be found in Appendix 3.1.

The forest management problem is framed according to the Model II timber harvest scheduling formulation (Johnson and Scheurman 1977). The notation used here closely follows that used by Dykstra (1984) and Armstrong and Cumming (2003). We use the objective function:

$$\text{maximize}\, NPV = \sum_{s=L,N,E} \sum_{k=1}^{K} \sum_{n}^{D} \sum_{j=-M+1}^{k} \frac{P_n v_{njk} - R_n x_{njk} - C_n x_{njk} - S_s y_{nsjk}}{(1+r)^{5j}} \qquad [3.1]$$

where the model chooses v_{njk}, x_{nj}, y_{nsj}, and where:

$NPV =$ net present value of timber production to the forestry firm

$L =$ leave-for-natural reforestation treatment

$N =$ native plantation reforestation treatment

$E =$ exotic plantation reforestation treatment

$K =$ the number of periods in the planning horizon

$D =$ the number of different development types

$M =$ age of oldest existing stand type, in periods

P_n = real per m^3 value of timber at the stump (i.e., stumpage value) from development type n

v_{njk} = m^3 of timber harvested from development type n, established in period j, and harvested in period k

R_n = real per hectare land procurement cost for development type n

x_{njk} = hectares in development type n established as exotic plantations in period j and harvested in period k

C_n = real per hectare exotic plantation conversion cost for development type n

S_s = real per hectare reforestation cost of treatment s

y_{nsjk} = hectares in development type n given treatment s in period j and harvested in period k

r = real interest rate

The following starting inventory constraints ensure all of the land is either harvested or not harvested:

$$\sum_{k=1}^{K} x_{njk} + \sum_{s=L,N,E} \sum_{k=1}^{K} y_{nsjk} + u_{nj} = A_{nj} \qquad [3.2]$$
$$n = 1, 2, \ldots, D; \quad j = -M + 1, -M + 2, \ldots, 0$$

where

A_{nj} = initial area (ha) of development type n established in period j

u_{nj} = area (ha) of land in development type n established in period j that is never harvested in the planning horizon

The following set of constraints ensures the area of each development type established in each period of the planning horizon equates to the area of the development type harvested in that period:

$$\sum_{l=k}^{K} x_{njl} + \sum_{s=L,N,E} \sum_{l=k}^{K} y_{nsjl} + u_{nk} = \sum_{j=-M+1}^{K} x_{njk} \qquad [3.3]$$

$n = 1, 2, \ldots, D; \quad k = 1, 2, \ldots, K$

The following volume flow constraints are used to control the variation in the harvest volume from one period to the next:

$$V_k = \sum_{n=1}^{D} \sum_{j=-M+1}^{k} v_{njk} \qquad k = 1, 2, \ldots, K-1 \qquad [3.4]$$

$$(1-\alpha)V_k - V_{k+1} \leq 0 \qquad k = 1, 2, \ldots, K-1 \qquad [3.5]$$

$$(1-\beta)V_k - V_{k+1} \geq 0 \qquad k = 1, 2, \ldots, K-1 \qquad [3.6]$$

$$V_k = \chi \qquad [3.7]$$

where

T_k = total volume (m^3) harvested in period k

α = maximum proportional decrease in total harvest volume from one period to the next

β = maximum proportional increase in total harvest volume from one period to the next

χ = harvest volume that must be harvested each period

For the even-flow analyses, α and β are set to zero. For policies that ensure the maximum sustained yield harvest is maintained, χ is set at the desired harvest level.

The following non-negativity constraints apply to each activity in the linear programming formulation:

$$x_{njk} \geq 0; \quad u_{nj} \geq 0; \quad T_k \geq 0; \quad \forall n, j, k \qquad [3.8]$$

Modelling assumptions

Equation 3.1 requires values for the following variables, all of which are inflation adjusted to 2004 dollars:

(i) Stumpage value (P). This is the stumpage value of timber to the representative forestry firm. We determine P_n by subtracting all the harvest and log-hauling costs associated with a particular development type from the price of timber received at the mill-gate. Our model is only concerned about timber volume, so there is no differentiation between different prices for wood quality. We begin by assuming an average gate-price for timber of $48.69/m^3 (WRI 2000).

We then subtract harvesting costs from the gate-price. Here we assume a cost of $3060/hectare for timber harvesting, road construction and log loading. We opt for an area-based cost because harvest costs are dependent on stand volume, and using a fixed area-based cost increases the per cubic meter harvest cost as stand volume declines.

Finally, for log hauling, we use a figure of $0.07/m^3/km (Kuhnke *et al.* 2002), which equates to log haul costs as shown in Table 3.1.

Table 3.1. Log haul cost from each haul zone.

Haul zone	Haul cost ($/m^3)
1	0.70
2	2.10
3	3.50
4	4.90
5	6.30
6	7.70
7	9.10
8	10.50
9	11.90
10	13.30

(ii) Real interest rate (r). Since timberland investments are believed to have a risk level similar to corporate bonds, a potential benchmark is the Aaa corporate bond yields in the United States, which between 1970 and 1999 yielded an average nominal interest rate of 9.1% in the wake of average inflation of 5.2% (Buongiorno and Gilless 2003). Since real dollars are used exclusively in this model, the real rate of return must be used as a discount rate. The real rate of return is calculated using the formula $1+r = (1+R)/(1+\pi)$, where r is the real rate of return, R is the nominal rate, and π is the inflation rate. In this case, the real rate of return is 3.7%.

(iii) Land procurement costs (R). We assume that whether exotic plantations are established on private or public land, there will be a procurement cost that the firm has to pay—i.e., procurement secures the property right to establish exotic plantations on either private or public land. On public land we assume a property right similar to grazing leases in Alberta, which can be procured for approximately $2/ha/year (SRD 2003). Since we assume that land converted to an exotic plantation stays an exotic plantation, we use the real interest rate of 3.7% to convert this perpetual payment into a lump sum present value cost of $50/hectare. For native species, however, we assume there are no public land procurement costs.

For private land, procurement could include either purchasing or leasing. For example, Alberta-Pacific Forest Industries Inc. (Al-Pac), which is one of the few boreal forestry firms establishing hybrid poplar plantations on an operational basis, procures land using long-term leases with Alberta landowners at a rate of $62/ha/year (Thomas and Kaiser 2003). Once again, since land converted to an exotic plantation stays an exotic plantation, we use the real interest rate of 3.7% to convert this annual payment into a lump sum present value cost of $1675/hectare. As an empirical check, this present value cost closely approximates the average purchase price for agricultural land around Al-Pac's mill, which for 2006 was $1750/hectare (Government of Alberta 2007).

For both private and public land, we assume that land is procured for the above costs, regardless of soil productivity. In other words, land with a good timber productivity rating costs the same as land with a rating of medium or fair. Therefore, when allocating land to exotic plantations, the model will first seek out good sites close to the mill.

(iv) Conversion costs (C). This value considers the costs incurred when the firm chooses to convert public land to an exotic plantation. In this case we assume native timber has been harvested and there will be costs to achieving a bare land state similar to private land. A previous Alberta study found that land clearing costs are approximately $300/hectare (Westworth and Associates 1994). This cost covers unearthing the stumps, as well as piling and burning them. Since land converted to an exotic plantation is assumed to stay an exotic plantation, the conversion cost is only paid once.

(v) Reforestation costs (S). As was the case for land procurement, we use the real interest rate of 3.7% to calculate the lump sum present values of all reforestation costs. For leave-for-natural reforestation, the present value cost of data management and monitoring is assumed to be $5/hectare (Insley *et al.* 2002).

For native plantations, $930/ha is assumed to cover the present value cost of site preparation, nursery stock, and planting (Insley *et al.* 2002).

For exotic plantations, Al-Pac's reforestation costs are provided by Thomas and Kaiser (2003), and when they are discounted to year zero and summed, the present value is \$1231/ha. In addition to this value, for exotic plantations we estimate that a post-harvest cost of \$175/ha will be necessary to unearth and burn the stumps after harvesting. Our estimate for this post-harvest cost is less than the \$300/ha public land conversion cost because we assume that once the land has been converted to a plantation, subsequent harvests of the short-rotation plantations will require less piling and burning.

Results

The model setup and non-spatial results are summarized in Table 3.2; the proportion of land allocated to each land-use is shown in Figure 3.5; and the spatial results are shown in Figure 3.6. For each policy, the model reaches a steady-state allocation of land to the different land-uses. This steady-state is achieved because (*i*) once land is converted to exotic plantation, it is forced to remain an exotic plantation, and (*ii*) there is an even-flow constraint on timber production. Spatial results are reported after the steady-state allocation of land is reached, which for all policies occurs before the end of the 200-year modelling period. The time path over which land is converted into exotic plantations is shown in Figure 3.7.

Table 3.2. Model setup and non-spatial results for each policy.[*]

Policy	Combine land bases?	Exotics on public land?	AAC (Mill. m^3/yr)	NPV ($Bill.)
MSY	N	N	2.2	0.9
PPZ	Y	N	2.2	1.4
PLACE	Y	N	5.0	2.1
MSY-PLE	N	Y	5.3	1.1
PPZ-PLE	Y	Y	5.3	2.6
PLACE-PLE	Y	Y	6.0	2.7

[*] Abbreviations are as follows: MSY is maximum sustained yield, PPZ is public-private zoning, PLACE is private land allowable cut effect, PLE is public land exotics, AAC is annual allowable cut, NPV is net present value, Y is yes, and N is no.

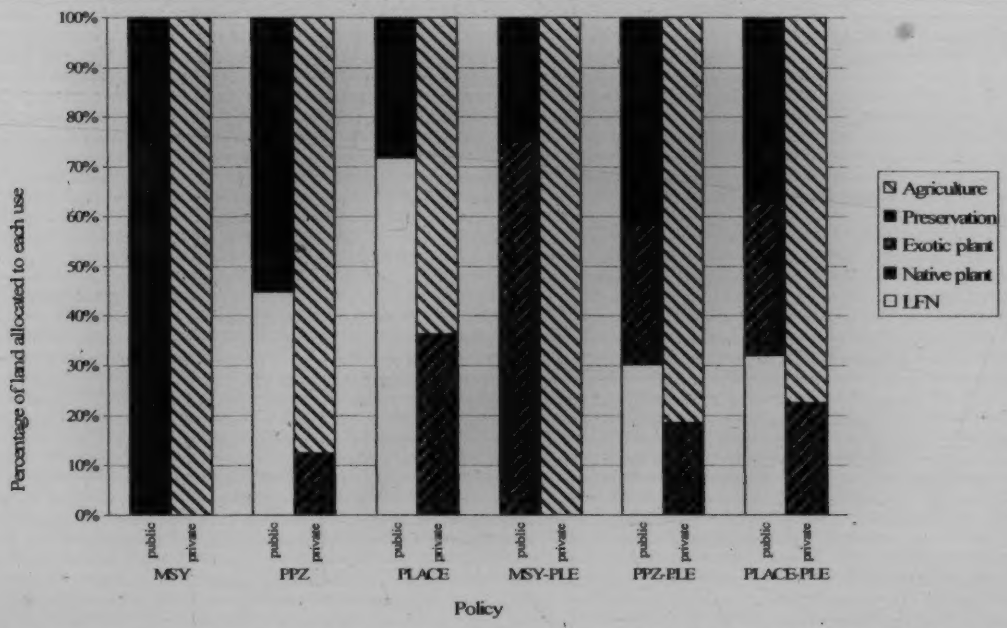


Figure 3.5. Proportion of private and public land allocated to the different land-uses for each policy.[*]

[*] Abbreviations are as follows: MSY is maximum sustained yield, PPZ is public-private zoning, PLACE is private land allowable cut effect, PLE is public land exotics, and LFN is leave for natural.

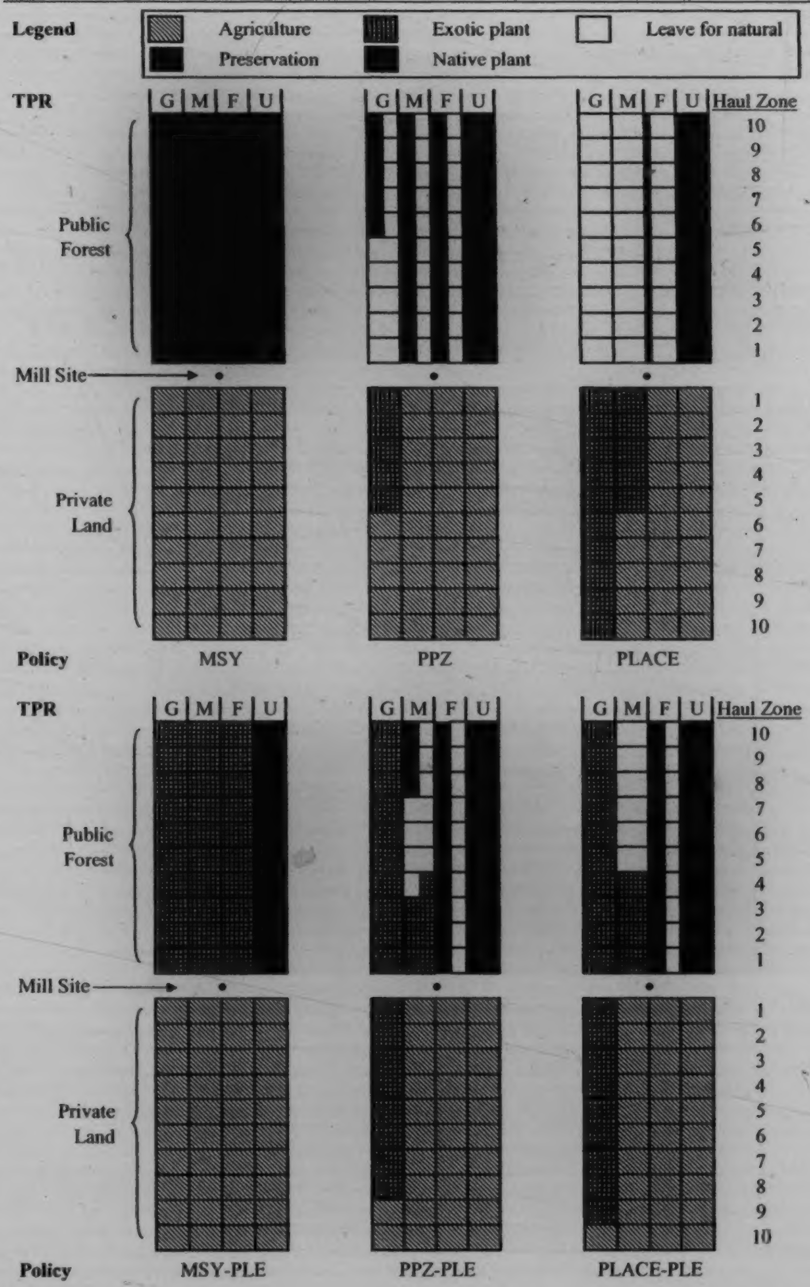

Legend
Agriculture
Exotic plant
Leave for natural
Preservation
Native plant
TPR
G M F U
Haul Zone
10
9
8
7
6
5
4
3
2
1
Public Forest
Mill Site
Private Land
Policy
MSY
PPZ
PLACE
MSY-PLE
PPZ-PLE
PLACE-PLE

Figure 3.6. Spatial allocation of public and private land to the different land-use zones.*

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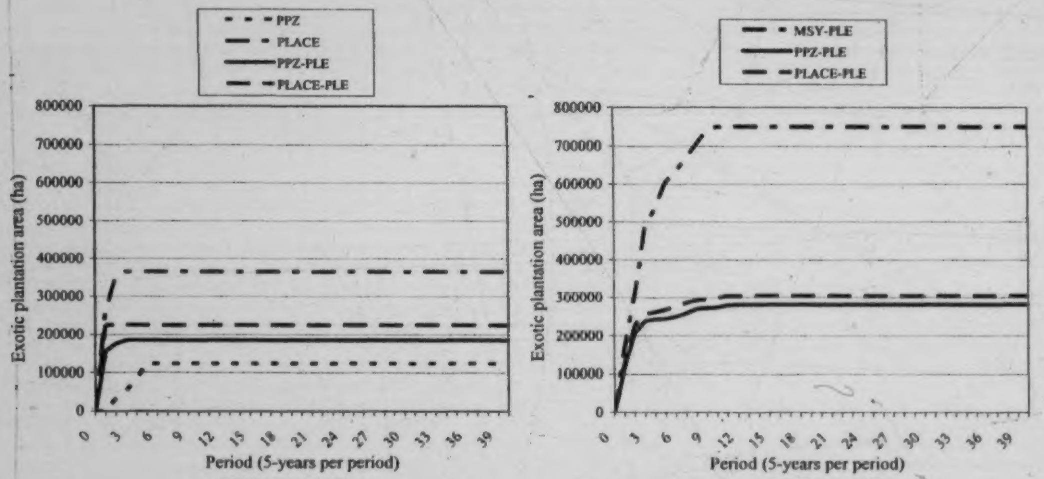
* Abbreviations are as follows: MSY is maximum sustained yield, PPZ is public-private zoning, PLACE is private land allowable cut effect, PLE is public land exotics, TPR is timber productivity rating, G is good, M is medium, F is fair, and U is unproductive. In cases where squares are divided into different land-uses, the width represents the proportion allocated to each use.



PRIVATE LAND

PUBLIC LAND

Figure 3.7. Exotic plantation area over time for private and public land.[*]

[*] Policies are abbreviated as follows: MSY is maximum sustained yield, PPZ is public-private zoning, PLACE is private land allowable cut effect, and PLE is public land exotics.

MSY policy: even-flow on public land; no exotics

For the MSY policy the model goes through two steps. For the first step the objective is maximizing the even-flow of timber from public land using only native species. In other words, the first step does not consider firm profitability. Instead, it is simply concerned with producing as much native timber as possible, which turns out to be 2.2 million m^3/year (Table 3.2). Then, the second step to the MSY policy considers the NPV of producing this AAC. Here the model uses Equation 3.1, but with the constraint that it must produce 2.2 million m^3/year, resulting in a NPV of $0.9 billion (Table 3.2).

The second step is necessary because there is usually more than one harvesting schedule that can produce the AAC calculated in step one. However, a harvesting schedule that concentrates in the short term on harvesting closer to the mill site will be more profitable than one that concentrates further away. So in the second step, the model searches for the most profitable way of producing the MSY harvest level using only native species on public land.

The model can use either LFN or native plantation, but since step one does not consider profitability, it allocates all productive land (i.e., 75% of the total public land) to the more expensive plantation alternative (Figure 3.6 and 3.7). The remaining 25% of the public land, which is unproductive, is preserved (Figure 3.5). Therefore the baseline preservation for our stylized forest is 25%.

This policy is not suggesting that firms should plant all their land, especially since we are modelling deciduous operators, many of which rely mainly on LFN (CFS 2006). Instead, it suggests that native plantations are better at maximizing AAC than LFN. For our stylized landscape, 2.2 million m^3/year is the maximum AAC the public land can produce using native trees, and $0.9 billion is the maximum NPV generated from producing it. Hence, we use these two values as a baseline for comparing the upcoming policies.

PPZ policy: even-flow on private and public land equal to MSY policy; exotics on private land

For the PPZ policy the model spatially allocates private and public land to the different land-use zones—LFN, native plantation, exotic plantation, or preservation—such that the firm's profits are maximized and the harvest level calculated in the previous MSY policy is produced. In other words, the 2.2 million m^3/year AAC is used as a constraint, which the model must satisfy while maximizing NPV (Equation 3.1). However, the model is now permitted to achieve the MSY harvest level by combining private land exotic plantations with the management of native species on public land.

Under this policy it is more profitable to reduce the overall forestry footprint by combining private and public land. More specifically, allocating 12.4% of private land to exotic plantations (Figures 3.5 and 3.7) results in an NPV of $1.4 billion; this is a 56% increase in NPV from the MSY policy (Table 3.2). These private land plantations are established on good sites in haul zones one to five—i.e., within 90 km of the mill (Figure 3.6). Also note that there are no longer any native plantations, as it is more efficient to produce timber using exotic plantations on private land and LFN on public land (Figures 3.5 and 3.6).

Since we are producing the same volume using less land, 55.2% of public land is now preserved—i.e., the 25% unproductive land plus an additional 30.2% of preservation (Figure 3.5). Another interesting result is that this preserved land is not just low productivity sites far from the mill. Instead, there are some good sites preserved in haul zones six to ten, as well as some fair and medium sites preserved in haul zones one to ten (Figure 3.6).

This wide range of preservation stems from the unbalanced age-class distribution of our stylized forest. The abundance of low yielding over-mature timber is expensive to harvest (because of the per hectare harvesting cost), making it more efficient to preserve these sites. For example, it is financially feasible to harvest and reforest the oldest stands on good sites in haul zones one to five, but once you get over 90 km from the mill it is better to preserve them. Generally speaking, stands 125-years and older are preserved, since it is at this age that native species of all TPRs begin experiencing declining yield

(Figure 3.3). It should be noted that this analysis assumes firms are managing pure deciduous stands. The presence of coniferous species will reduce overall tree mortality, and therefore reduce the rate at which stand yield declines. In other words, preserving an over-mature stand with coniferous species will be less profitable than if it were pure deciduous, *ceteris paribus*.

PLACE policy: even-flow on private and public land; exotics on private land

For the PLACE policy the model imposes sustained yield on the combined private and public land base, but this time without the MSY constraint on AAC. In other words, we allow investment in private land exotics to accelerate the harvest of mature timber on public land. The model determines the even-flow of timber from the combined land base which maximizes NPV (Equation 3.1). It allocates private land to exotic tree plantations whenever profitable, and as land becomes further from the mill site the increasing log-haul costs eventually impose a feasibility frontier.

As expected, combining private land exotic plantations with public land activates an ACE, which increases the AAC 127%—from 2.2 to 5.0 million m^3/year (Table 3.2). This AAC increase generates an NPV of $2.1 billion, which is a 133% increase over the $0.9 billion for the MSY policy, and a 50.2% increase over the $1.4 billion for the PPZ policy.

Although the PLACE policy is financially superior to the PPZ policy, the profits come at a cost to preservation, as only 28.1% of land is preserved—i.e., 3.1% of productive land is preserved in addition to the 25% unproductive (Figure 3.5). At first, the presence of any preservation at all is somewhat surprising. But as was the case with the PPZ policy, this outcome is related to the abundance of over-mature timber in the starting forest. The per hectare harvesting cost makes low yielding old-growth expensive to harvest, making it more efficient to preserve these sites. In this case, fair site stands 140-years and older, which yield less than 100 m^3/ha (Figure 3.3), are preserved in all ten haul zones (Figure 3.6).

Compared to the PPZ policy, exotic plantations are more rapidly established under the PLACE policy (Figure 3.7), enabling a more rapid liquidation of the mature timber. This rapid liquidation moves the revenue into earlier time periods, thus improving the financial feasibility of harvesting these old stands. The cost to preservation, however, is that the proportion of public land preservation decreases from 55.2% under the PPZ policy to 28.1% under the PLACE policy (Table 3.2).

The benefits from the ACE are direct result of the constraints imposed by sustained yield. The higher the costs of the sustained yield constraints, the higher will be the potential returns to the ACE (Binkley 1980). Although the policies recommended in this chapter assume sustained yield as an underlying policy, we are nonetheless curious as to the shadow price of the sustained yield constraint. When the model is rerun without the sustained yield constraint, there is a 167% increase in NPV (i.e. to \$2.4 billion) over the \$0.9 billion for the MSY policy, indicating substantial potential returns for the PLACE policy.[15] Along these lines, we find the NPV for the PLACE policy to be \$2.1 billion, eliminating almost all of the cost of the sustained yield constraint.

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[15] Without the sustained yield constraint there is significant variability in the harvest levels. All of the standing timber older than 85-years is harvested in the first period, leading to a first period AAC of 15.8 million m^3/year. Such rapid liquidation is a result of the profit maximizing objective function, which maximizes NPV by generating profits as quickly as possible. Having converted so much over-mature timber to regenerating stands, there is a long lag before significant volume becomes available for harvest. Indeed, the AAC for the second and third periods are only 0.26 million and 0.22 million m^3/year, respectively. Then some private land plantations become available, and harvest levels start rising again—

MSY-PLE policy: even-flow on public land; exotics on public land

We model the MSY-PLE policy the same as for the previous MSY policy, except we now allow the model to use exotic plantations on public land. As was the case with the previous MSY policy, the first step of this policy considers only volume, and the second step maximizes the NPV (Equation 3.1) of producing the MSY AAC.

Since the objective in this policy is to maximize AAC, the model allocates all of the productive land to exotic plantations, which are the most productive. And as was the case with the previous MSY policy, the remaining 25% of the public land, which is unproductive, is preserved (Figure 3.5). The AAC of 5.3 million m^3/year leads to a NPV of $1.1 billion (Table 3.2). Comparing the MSY-PLE policy with the MSY policy—with its AAC of 2.2 million m^3/year and NPV of $0.9 billion—suggests that PLE increases harvest by 141% and NPV by 22%.

PPZ-PLE policy: even-flow on private and public land equal to MSY-PLE; exotics on public and private land

We model the PPZ-PLE policy by maximizing NPV (Equation 3.1) while forcing the model to maintain the AAC of 5.3 million m^3/year (as calculated in the previous MSY-PLE policy). In addition, we allow the model to combine public and private land, and hence use private land exotics to produce the required AAC if it is more profitable than using only public land. And once again there is an increase in profits from reducing the forestry footprint. The NPV increases 136% when comparing MSY-PLE to PPZ-PLE—

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only to be followed by another drop. An up-and-down cycle of harvests continues throughout the planning horizon. Mill requirements and costs associated with surge harvests would likely preclude such harvesting patterns as a possibility.

from $1.1 billion to $2.6 billion, respectively—because the model now allocates 18.5% of private land to exotics (Table 3.2 and Figure 3.5). These plantations are only established on good sites in haul zones one to eight—i.e., within 150 km of the mill (Figure 3.6).

Reducing the forestry footprint also causes an additional 16.8% of public land to be preserved, such that the total preservation is 41.8% (Figure 3.5). In this case there are fair sites in all haul zones preserved, as well as medium sites preserved in haul zones eight to ten. In contrast to the PPZ policy, this time there are no good sites preserved (Figure 3.6). Indeed, comparing the PPZ policy with PPZ-PLE suggests that public land exotics lead to 13.4% less forest preservation, but 86% more profits (Table 3.2 and Figure 3.5).

The absence of exotic plantations on fair sites suggests the feasibility of exotic plantations is sensitive to TPR. Instead, plantations occur on good sites all the way to haul zone ten on public land and to haul zone eight on private land (Figure 3.6). Public land exotic plantations also occur on medium sites, but only between haul zones one and four. There are more exotic plantations on public land than on private land because it is cheaper to procure.

Once again, there are no native plantations (Figure 3.5). Public land not preserved or under exotic plantations is managed as LFN. This finding stems from the large difference in growth rates between exotic and native plantations relative to the small difference in cost.

PLACE-PLE policy: even-flow on private and public land, but no volume constraint; exotics on public and private land

We model the PLACE-PLE policy by having the model choose the even-flow AAC that maximizes NPV, while still allowing the combination of private and public land. Not surprisingly, this policy yields the highest NPV and AAC, at $2.7 billion and 6.0 million m^3/year, respectively (Table 3.2).

Comparing the PLACE policy with PLACE-PLE, we are not surprised that public land exotics increase profits by 29% and AAC by 20% (Table 3.2). What is surprising, however, is that 12.5% of productive land is preserved when modelling PLACE-PLE, compared to the 3.1% preserved when modelling only the PLACE (Figure 3.5). The difference arises because the ACE enables the rapid establishment of exotic plantations close to the mill site (Figure 3.7). Since this exotic timber matures so quickly, it is once again more efficient to reduce the overall forestry footprint and preserve the distant stands of over-mature native timber. In this case, fair site stands 120-years and older, which have begun experiencing declining yield, are preserved in all ten haul zones (Figure 3.6).

Once again, the benefits from the ACE are a result of the constraints imposed by sustained yield. When the model is rerun without the sustained yield constraint, there is a 182% increase in NPV (i.e. to $3.1 billion) over the $1.1 billion for the MSY-PLE policy, indicating substantial potential returns for the PLACE-PLE policy. Along these lines, we find the NPV for the PLACE-PLE policy to be $2.7 billion, eliminating almost all of the cost of the sustained yield constraint.

Discussion

Our modelling suggests current tenure systems require reforestation efforts that are inconsistent with both profit maximization and forest preservation. Specifically, we find significant costs associated with "use-it-or-lose-it" policies. There also appears to be costs associated with policies preventing public land exotics. These findings add support to previous work by Luckert and Haley (1993), who suggest that "Canadian forest policies encourage behaviour in private firms which may significantly reduce the value of public forest resources."

"Use-it-or-lose-it" policies currently cause inefficiently large forestry footprints. Giving firms options for reducing their foresty footprint seems to improve profits and preservation. Such efficiency gains arise because profitability is somewhat related to log-haul distance. Our model suggests reducing the forestry footprint with exotic plantations, whether on private or public land, increases profits. And as an added bonus, public land no longer required to feed the mill can be preserved. But even though MSY harvest levels could be maintained, preserving more land would require provincial governments to forego increasing timber production beyond MSY levels—something they might be unwilling to do.

Provincial governments hesitant to forego future increases in harvest levels by increasing preservation might be interested in policies such as the PLACE. These policies not only lead to an increase in the public land harvest beyond MSY levels—therefore increasing government revenues from taxes and timber dues—but they also lead to an increase in preservation.

As was mentioned in Chapter 2, the ACE has advantages and disadvantages. The benefits to the ACE only arise because of the significant costs of the sustained yield constraint (Binkley 1980). Moreover, implementation of ACE policies may not be advisable because of their potential distortions on forest management and harvesting decisions, and their potential to prolong the continuance of anachronistic sustained yield policies (Luckert 2001). However, results of our simulations indicate that the inclusion of ACE provisions eliminate almost all of the shadow prices of sustained yield, while preventing surge cutting behaviour. Although beyond the scope of this thesis, future research should more fully explore the social implications of ACE policies within the context of triad.

Although public land exotic plantations are common elsewhere, they are almost nonexistent in Canada. Such policies infer a trade-off between biodiversity and preservation, such that low biodiversity exotic plantations are exchanged for high biodiversity preserves. And while some do not support such a trade-off, it is being discussed more and more.

A somewhat unexpected result is that preserves are not simply allocated to poor land located far from the mill. Yield-dependent harvest costs and the abundance of low yielding old stands combine to preserve some over-mature stands on good and medium sites within various haul zones. Preserving over-mature stands for environmental and financial reasons differs from current forest policies, which often require the oldest stands be harvested first. Instead, our modelling suggests harvesting should focus on middle-aged stands that have not yet experienced such high mortality. Then by regenerating these areas with native LFN or exotic plantations, the oldest stands are preserved and the forestry sector made more competitive. Society benefits from preservation and profits.

Such zoning emphasizes land-use specialization, which differs from Canada's current emphasis on multiple-use management. Vincent and Binkley (1993) argue against multiple-use, suggesting it is inefficient in generating both timber and non-timber products. Our findings support this argument by suggesting that policies which enable firms to pursue priority-use zoning could solve such inefficiencies.

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CHAPTER 4. INTERNATIONAL-LEVEL ANALYSIS

Introduction

Between 1992 and 2003, the global area under preservation increased 52.8%, such that the terrestrial proportion of the globe managed as preserves in 2003 was 11.5% (Chape *et al.* 2003). The purpose of such preservation is to maintain biological diversity and protect natural and associated cultural resources (IUCN 1983). Preservation areas, also known as parks, are protected though legal and other effective means. Meanwhile plantation forestry, which was negligible as late as the 1950s, increased to an estimated 34% of global timber production by 2000 (Sedjo 2003).

The increase in preservation could be dependent on the increase in plantations. Indeed, a premise of priority-use zoning is that the increased productivity of plantations allows for more preservation without a decrease in timber production (e.g., Messier 2007)—which raises the question: Do plantations promote preserves? Or more specifically, is plantation forestry a technique whereby countries increase their area of preserved forest? To address these questions, we use data from a cross-section of countries to investigate whether plantation forestry is a determinant of forest preservation.

Our interest in plantation forestry as a determinant of preservation stems from studies suggesting that even as global demand for timber rises, it is possible to preserve more forestland in the future. The potential for a relationship between plantations and preserves is well documented. Roger Sedjo (1999) has said that if environmentalists are to be appeased, "it must be demonstrated that plantation forestry can serve a protective function for native forests." David Victor and Jesse Ausubel (2000) described "The Great Restoration", by which the world's natural forests will be restored because "efficient farmers and foresters are learning to spare forestland by growing more food and fiber in ever-smaller areas." Christian Messier (2007) also recommends using plantations to promote preserves, suggesting that in Canada, "one hectare of hybrid poplar can ... be used to put aside 5 to 14 hectares of forest for other purposes."

These studies are based on the logic that slow-growing natural forests can be preserved by establishing fast-growing plantations. The authors propose that the major mechanism of preservation is that increased timber production from plantations will allow more natural forest to be preserved. For example, governments may be more likely to preserve forested areas if they are convinced that improved technology associated with plantations can make up the forest products shortfall. If increased productivity from plantations reduces prices of forest products, then opportunity costs for governments to set aside forested areas may be reduced.

However, it is also possible that more plantations will not lead to the preservation of forests. Rather, new technology associated with plantations could also reduce incentives to preserve forest land as economic returns motivate greater plantation areas, but with no decrease in wood product prices. In other words, industrial forest land values and opportunity costs of forest preservation could remain high, making it more difficult to preserve forests.

In this chapter, we empirically investigate the relationship among a number of potential determinants of preservation, including composition and scale of economies, income, trade, institutions, and technique. To investigate these determinants we use a reduced-form model. The model posits a relationship between a variable—in our case forest preservation—and various exogenous variables, but without a structural theoretical model of the underlying relationships (e.g., Grafton *et al.* 2004). In the remainder of this chapter, we review the literature for insights into reduced form modeling and forest preservation. We then specify an empirical model, highlight the data, and discuss some econometric issues. Finally, we state our results and conclude with a brief discussion.

Determinants of forest preservation

There are four literatures which use a reduced-form approach to provide insights on the economics of forest preservation. These literatures: *(i)* correlate explanatory factors with deforestation, *(ii)* detail the environmental Kuznets curve (EKC), *(iii)* estimate the impact of trade on the environment, and *(iv)* investigate the impacts of institutions (i.e., good governance) on the environment. The deforestation literature suggests that forest conversion is an important factor in fueling the economic growth of developing countries (Naidoo 2004). This result agrees with the "classic" finding of the EKC literature, that environmental quality initially decreases with rising per-capita income. But as income rises, environmental degradation eventually reaches a turning point, after which environmental quality begins to rise (e.g., Grafton *et al.* 2004). These types of EKC findings are also found in the trade and environment literature for some forms of environmental quality and for some regions (e.g., Frankel and Rose 2005). This relationship can arise when there are income effects, technique effects (i.e., changes in technology) or composition effects (i.e., changes in the mix of economic activities) that result in improved environmental quality and increased income (Copeland and Taylor

2004). Therefore it is possible that trade, which promotes economic growth, may have a beneficial effect on some measures of environmental quality (Frankel and Rose 2005). It is also possible that good governance is necessary for achieving increases in environmental quality (Deacon 1994).

In general, these four literatures test whether environmental quality is related to factors such as income, time, trade, population density and polity. Applying the general results from these four literatures to forest preservation, we are left to question whether given the impacts of institutions, the increased productivity from plantation forestry could not only increase income and trade, but could also increase environmental quality by encouraging forest preservation—i.e., a technique effect.

Environmental quality has been hypothesized to be affected by the following factors (e.g., see Copeland and Taylor 2003):

1. *composition effects:* changes in the mix of economic activities
2. *income effects:* changes in per capita income
3. *trade effects:* changes in trade patterns
4. *institutional effects:* changes to rules, laws
5. *scale effects:* changes in the scale of an economy
6. *technique effects:* changes in technology

Our main objective is to empirically investigate the presence of a technique effect in the form of plantation forest management. Given that a technique effect could generate an EKC with respect to forest preservation, we also test for the presence of an EKC. Finally, we look for evidence that forest preservation is affected by other major effects, such as composition, scale, trade, or institutions.

The empirical model

To examine factors affecting the area of preserved forestland, our model is as follows:

$$\begin{aligned} Preserved_{00,i} = {} & \alpha_0 + \alpha_1 (LandArea)_{00,i} + \alpha_2 (Forestry/Y)_{00,i} \\ & + \alpha_3 (Y/pop)_{00,i} + \alpha_4 [(Y/pop)_{00,i}]^2 + \alpha_5 \ln(M^F)_{00,i} \\ & + \alpha_6 (Polity)_{00,i} + \alpha_7 (Ownership)_{00,i} \\ & + \alpha_8 (Forestry/ForLand)_{00,i} + \beta (Plantation)_{00,i} + \varepsilon_i \end{aligned} \qquad [4.1]$$

where:

$Preserved_{00,i}$ = hectares of preserved forest in the year 2000 for country *i*

$\{\alpha_i\}$= a set of coefficients

$LandArea_{00,i}$ = total hectares of land in the year 2000 for country *i*

Forestry/Y = ratio of forestry value-added to GDP

Y/pop = per capita income

$\ln(M^F)$ = natural logarithm of forestry imports

Polity = a measure of how democratic (versus autocratic) the government is

Ownership = proportion of forest that is publicly owned

Forestry/ForLand = ratio of forestry value-added to total forestland

Plantation = hectares managed as forest plantations

ε = the residual representing other causes of forest protection

To control for the fact that large countries often preserve more forest, we include country size as an explanatory variable.[16] The remaining explanatory variables are present to capture one of the six aforementioned effects, should they exist. The coefficient of most interest to us is β, which, if significant and positive, suggests a technique effect. Also important is estimating whether there is an EKC with respect to forest preservation, since it is possible that the technique effect is a component—along with the other effects—of an aggregate trend towards an EKC. It is also possible that the presence of plantation forestry causes shifts in the EKC. Therefore in addition to the specification noted in Equation 4.1, we also investigate interactions between the *Plantation* variable and the variables *Y/pop* and *Ownership*. Finally, we also employ instrumental variables to address potential endogeneity issues. These interaction effects and endogeneity concerns are discussed below under "Econometric Issues."

Data collection

Basic statistics and expected signs for all variables used in our analysis are summarized in Table 4.1. Unfortunately, our reliance on secondary data (described below) yields a complete dataset of only 21 countries. The complete dataset can be found in Appendix 4.1. A sample of this size is less than ideal, but reliable data for the key variables do not exist for all countries. Not surprisingly, the reliable data that do exist are from countries that are reasonably developed. Without data from developing countries, our dataset has low variance for some variables, such as *Polity*. This dataset limits our findings such that they should be applied carefully, and only to countries that are somewhat developed and democratic.

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[16] We also explored using proportions and log-odds as the dependent variable, but did not proceed further because of the poor statistical performance of these specifications.

Table 4.1. Variables used in regression models (N=21).

Variable (units)	Abbreviation	Mean	Std. Dev.	Min.	Max.	Expected Sign
DEPENDENT VARIABLE						
Total area of preserved forest (000 ha)	*Preserved*	6474.7	15495.0	6.59	66668.0	n/a
INDEPENDENT VARIABLES						
Control Variable						
Total land area (000 ha)	*LandArea*	181800	424570	3392	1688900	+
Composition Effects						
Forestry value added/GDP	*Forestry/Y*	0.0118	0.0075	0.0050	0.0393	-
Income Effects						
Real GDP per capita (US$)	*Y/pop*	20116	9015	5024	35619	-
[Real GDP per capita (US$)]^2	$(Y/pop)^2$	4.8E+08	3.5E+08	2.5E+07	1.3E+09	+
Trade Effects						
ln(Forestry imports (million US$))	$ln(M^F)$	7.407	1.429	4.837	10.154	+
Institutional Effects						
Polity (-10 [autocracy] to +10 [democracy])	*Polity*	9.429	1.028	7	10	+
Proportion of forestland publicly owned	*Ownership*	0.5561	0.2836	0.073	1.0	+
Scale Effects						
Forestry value added/Forestland (000 US$/ha)	*Forestry/ForLand*	1.0705	1.6013	0.0021	6.3544	-
Technique Effects						
Total area of plantations (000 ha)	*Plantation*	2721.3	5197.9	4.0	17340	+/-
INSTRUMENTAL VARIABLES						
Total area of forestland (000 ha)	n/a	64597	188910	375.0	8.5E+05	n/a
Real GDP per capita, 1995 (US$)	n/a	16079	7075	4700	27895	n/a
[Real GDP per capita, 1995 (US$)]^2	n/a	3.1E+08	2.2E+08	2.2E+07	7.8E+08	n/a
Geographical trade gravity predictions	n/a	19.239	11.075	2.56	35.84	n/a

The dependent variable, *Preserved*, are the total areas of forest that are protected through legal or other effective means. These data are from the Food and Agriculture Organization (FAO 2001) of the United Nations.

In the following paragraphs we explain how the explanatory variables reflect the various effects discussed in the previous section, and we describe our data sources.

1. Composition effects

Recall that composition effects are from changes in the mix of economic activities. To capture these effects, we use data from Lebedys (2004) which gives the proportion of the forestry sector value-added[17] to GDP. These data are represented in Equation 4.1 as the explanatory variable *Forestry/Y*. We expect this explanatory variable to have a negative sign, since countries where the forestry share of GDP is high will likely focus on timber production, to the detriment of forest preservation.

2. Income effects

We expect that forest preservation will at first decrease in per-capita income, but will reach a turning point, after which it will rise as per the "classic" EKC. To capture such non-linear behavior, we use data from Penn World Table 6.1 to estimate a quadratic form of per-capita income. These data are represented in Equation 4.1 by the explanatory variables Y/pop and $(Y/pop)^2$. If an EKC is present, the sign on Y/pop will be negative, and the sign on $(Y/pop)^2$ will be positive.

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[17] The use of value added as a measure of forestry sector production by Lebedys (2004) is a change from previous FAO studies, where the simpler methodology was to multiply the quantity of processed forest product production by the value of production (using international trade prices). This new method incurs less bias since the use of international trade prices and the calculation of the gross value of production (rather than value-added) led to an over-estimate of the contribution of the sector to GDP.

3. Trade effects

Since forestry imports could substitute for local timber production, we expect forest preservation to increase as imports increase. These data, from Lebedys (2004), are represented in Equation 4.1 as the explanatory variable $\ln(M^F)$.

4. Institutional effects

Forest preservation is usually mandated by governments, thus we expect it to be dependent on institutions. There is evidence that environmental quality can be adversely affected by insecure property rights (Deacon 1994) and corruption (Pellegrini and Gerlagh 2006), so we expect that the more democratic a country, the more forest it will preserve. To capture this relationship we use polity data on political regime characteristics (Polity IV 2003). These data, represented in Equation 4.1 as the explanatory variable *Polity*, are a scale from -10 to +10. A measure of +10 indicates a strongly democratic state; a measure of -10 indicates a strongly autocratic state.

Another institutional effect could be driven by forest ownership. Here we expect countries with higher proportions of public forest to preserve more, since it is easier for governments to preserve forests when they do not have to negotiate with private landowners. To capture this effect we use forest ownership data (FAO 2006), which are represented in Equation 4.1 by the explanatory variable *Ownership*.

5. Scale effects

Since preserved forestland does not contribute to timber production, we expect countries which produce more forest products per hectare of forest land to have lower levels of forest preservation. To capture this effect we use data from Lebedys (2004) on the total forestry sector value added, as well as data from the FAO (2001) on the size of each country's forest. Dividing these two values yields the ratio of forestry value-added to total forestland. These data are represented in Equation 4.1 by the explanatory variable *Forestry/ForLand*.

6. Technique effects

We consider plantation forestry to be a technologically advanced form of forest management, and our main question asks whether plantations promote forest preservation by providing a technique that allows for increases in preservation areas without losses in forestry output. To capture this effect we use data from the FAO (2001) on a country's plantation area. In this case plantations are defined as reforested stands of even age class that are regularly tended. These data are represented in Equation 4.1 as the explanatory variable *Plantation*.

Econometric issues

Before estimating Equation 4.1, we address the issues of endogeneity, unobserved heterogeneity, and interaction effects.

1. Addressing potential endogeneity

It is possible that some variables not only affect the level of forest preservation, but may also be simultaneously affected by it. We address this endogeneity problem by using instrumental variables which are exogenous, yet highly correlated to the variables of concern. Then we compare the results between instrumental variable (IV) estimation and ordinary least squares (OLS) estimation. Similar results between the two approaches would suggest that endogeneity is not a significant concern.

As mentioned above, testing for endogeneity requires an instrumental variable which is exogenous, yet highly correlated with *Plantation*. For our instrument we use the total area of forestland. Plantation area is correlated with forestland area, but independently so, as plantation investments tend to be more dependent on income (Naidoo 2004), institutions (Deacon 1994) and future demand for timber (Bacha 2003).

With respect to other measures of environmental quality, the endogeneity of both income and trade are well documented (Rodrik 1995). Following the example of Frankel and Rose (2005), we use lagged income for the year 1995 as an instrument for Y/pop_{00}, and we use the predictions from a geographical trade gravity model (Frankel and Romer 1999) as an instrument for $\ln(M^F)$.

To summarize: we assess whether endogeneity affects this study by using the above instrumental variables (see Table 4.1) in IV estimation, and comparing the results to OLS estimation.

2. Addressing potential unobserved heterogeneity

Our use of a pure cross-section approach means we cannot control for unobserved heterogeneity. Typically, such heterogeneity comes from characteristics of individual countries that are difficult to capture. One approach to dealing with unobserved heterogeneity is to use panel data. In our case, however, problems with the panel data would limit the sample size to only ten countries. And our use of the trade gravity estimate as an instrument for the oft-endogenous trade variable would not fit within a panel model, since the instrument is static. Therefore, we follow the example of other studies (e.g., Frankel and Romer 1999, Frankel and Rose 2005) and use the trade gravity instrument in a cross-section approach.

3. Addressing potential interaction effects

It is possible that forest preservation is determined by interactions between explanatory variables. It is especially plausible that plantations would shift an EKC, should it exist. Therefore, to test whether there are any significant interaction effects, our initial estimates of Equation 4.1 included interaction terms between the variable *Plantation* and the variables *Y/pop* and *Ownership*.[18]

Results

Table 4.2 reports our key results for OLS and IV estimates. A Hausman test ($m = 1.618$) suggests there is no statistically significant difference between the OLS and IV coefficients, so endogeneity is not a concern. This absence of endogeneity makes the OLS estimation more appropriate. Hence, we discuss only the OLS results.

As previously mentioned, each variable in Equation 4.1 represents a particular effect as identified in the literature. In this analysis, however, some coefficients are not significantly different from zero. These include the coefficients for composition, scale, technique, and the institutional effect of public land ownership. All other variables are significant determinants of forest preservation. The regression model is highly significant ($F = 15.5$) and explains about 93% of the variance in forest preservation.

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[18] We found that none of the interaction terms were statistically significant, so they were eliminated from the model.

Table 4.2. Determinants of forest preservation.

Determinant	Abbreviation	OLS	IV
Control Variable			
Total land area	*LandArea*	0.02639***	0.04176***
		(0.00625)	(0.01287)
Composition Effects			
Forestry value added/GDP	*Forestry/Y*	303260	416070
		(198260)	(307840)
Income Effects			
Real GDP per capita	*Y/pop*	-4.3387***	-5.1018**
		(1.0789)	(1.6697)
(Real GDP per capita)^2	$(Y/pop)^2$	0.000108***	0.000127***
		(0.000023)	(0.000036)
Trade Effects			
ln(Forestry imports)	$ln(M^F)$	4676.6**	5811.6*
		(1519.8)	(2935.3)
Institutional Effects			
Polity	*Polity*	6251.5**	5393.4
		(2503.4)	(3639.2)
Proportion of forestland publicly owned	*Ownership*	4365.7	520.88
		(7671.9)	(11465.0)
Scale Effects			
Forestry value added/Total forestland	*Forestry/ForLand*	-1272.6	-1073.0
		(981.12)	(1427.3)
Technique Effects			
Total plantation area	*Plantation*	-0.02081	-1.6409
		(0.50501)	(1.1988)
Observations		21	21
R^2		0.93	0.85
Adjusted R^2		0.87	0.73

Multi-country estimation across countries in 2000. (Standard errors in parentheses.) Intercept included but not reported. * 10% level of significance. ** 5% level of significance. *** 1% level of significance. Instruments are as follows: for plantation area we use total forestland area; for income we use lagged income; and for trade we use predictions from a geographical trade gravity model.

Our main question asks whether there is evidence of a technique effect. Such an effect would be represented by a positive sign on β—the estimated coefficient for *Plantation*. Instead, β is negative, and it is not statistically significant. Therefore, our dataset does not provide evidence of a technique effect. This finding is supported by Figure 4.1, which shows that after controlling for a country's size, there is little visual correlation between plantations and preserves.

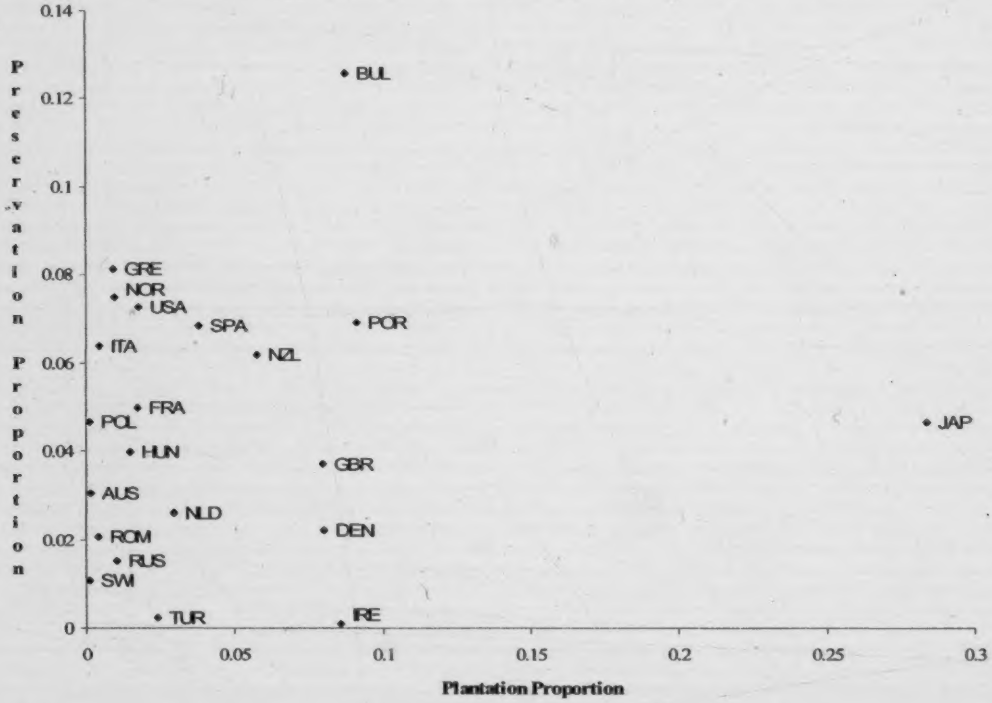

Figure 4.1. Proportion of a country allocated to preservation and plantations, 2000.[*]

[*] Abbreviations are as follows: BUL is Bulgaria, GRE is Greece, NOR is Norway, USA is the United States of America, SPA is Spain, ITA is Italy, NZL is New Zealand, POR is Portugal, FRA is France, POL is Poland, HUN is Hungary, AUS is Australia, NLD is the Netherlands, ROM is Romania, RUS is the Russian Federation, SWI is Switzerland, TUR is Turkey, IRE is Ireland, DEN is Denmark, GBR is Great Britain, and JAP is Japan.

Our secondary question asks whether there is an EKC for forest preservation. Both Y/pop and $(Y/pop)^2$ are statistically significant at the 1% level, and the signs on the estimated coefficients—negative and positive, respectively—are as expected. Hence, our dataset provides evidence of an EKC. Forest preservation seems at first to decrease in per-capita income, but reaches a turning point at around US$20 500, after which it rises. Consider, for example, if a country were to increase its per-capita income from the minimum value in our study (US$5 024) to the maximum value in our study (US$35 619). In this case our results for the income effect suggest the country's forest preservation would increase by approximately 1.5 million hectares.

The estimated trade effect of the $\ln(M^F)$ coefficient is positive, as expected, and significant at the 5% level. This result suggests imports are a substitute for local timber production, thus freeing forestland for preservation. For example, if the average country in our study, which imports around US$1.6 billion worth of forest products, was to double its imports, it would increase its forest preservation by almost 50%. In this case average forest preservation would increase from 6.475 million hectares to around 9.7 million hectares.

The estimated institutional effect of the *Polity* coefficient is positive, as expected, and significant at the 5% level. This result suggests the more democratic a country, the more forest it will preserve. Consider a particular country that was able to increase its polity from the minimum value in our study (7) to the maximum value in our study (10). Our results for the institutional effect suggest that such a shift would increase forest preservation in that particular country by around 18.8 million hectares.

In terms of relative importance, the effect of the EKC is not substantial. Moving from minimum to maximum polity has an order of magnitude larger effect than moving from minimum to maximum income. Similarly, doubling imports results in twice as much preservation as moving from minimum to maximum income.

Conclusions

In this chapter we have modeled the effect of plantations on preservation, controlling for country size and other relevant factors. We have conducted this modeling while using instrumental variables to account for the possible endogeneity between preservation and three explanatory variables: *i)* plantations, *ii)* income, and *iii)* forestry imports. The similarity between the IV and OLS estimates suggests endogeneity is not a significant concern.

There is statistically significant evidence of income, trade and institutional effects. The income effect suggests that there is an EKC for forest preservation. This finding agrees with a recent study that found evidence of an EKC for the "Forest Identity"—which is an index which relates a country's carbon sequestration to its growing stock of timber and biomass (Kauppi *et al.* 2006). The downward sloping portion of our EKC, where preservation areas are decreasing, also agrees with previous findings that poorer countries might use deforestation as a means of stimulating economic growth (Naidoo 2004). The upward sloping portion of the EKC suggests that development increases preservation.

The trade effect suggests that as a country imports more forest products, it tends to increase its forest preservation. This result agrees with previous work suggesting that

Finland and China are offsetting timber lost to increased protected areas by importing timber from Russia (Mayer *et al.* 2005). Policy-makers should be wary, however, that encouraging forestry imports could have global implications for preservation—i.e., importers could gain forest preservation at the expense of exporting countries, which are drawing down forest stocks and perhaps losing the option of setting aside such areas.

The institutional effect suggests that democracies preserve more forest. Assuming that democracy and property right security are positively correlated, this result agrees with previous findings that insecure property rights can lead to deforestation (Deacon 1994). In our case, insecure property rights seem to prevent preservation. Perhaps countries with insecure property rights have fewer forests left to preserve, or perhaps they lack the capability to enforce preservation.

To summarize: The lack of support for a technique effect suggests that plantations do not promote preservation. In other words, the increased timber production from plantations does not seem to be a mechanism by which increases in forest preservation arise. Rather, plantations and preservation appear to be independent. The global increase in plantations is likely a result of rising economic rents, whereas the global increase in forest preservation is likely a result of increases in development, democracy, and the import of forest products. Therefore, it appears as though increasing forest preservation arises from trade, institutions, and increasing the general level of development in countries, rather than increasing the specific level of technological development found in forest plantations. Those wishing to increase forest preservation without relying on imports are more likely to face the difficult task of promoting prosperity rather than promoting plantations.

Though plantations do not seem to have played a role in preservation historically, they could still play a role in the future. For example, current policies in Canada are believed to discourage plantation forestry (Anderson and Luckert 2007). If governments want fast-growing plantations to off-set slow-growing natural forests, policy reform may be required.

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CHAPTER 5. CONCLUSION

Although it is not unanimous, more and more environmental scientists support using fast-growing hybrid plantations to preserve slow-growing natural forests (e.g., Messier 2007). Such forms of priority-use zoning have been touted as a means of maintaining jobs while at the same time increasing preservation (Gladstone and Letig 1990, Hunter and Calhoun 1996, Binkley 1997). Yet within Canada this idea has gained little traction among governments, industry, and the public. This thesis adds to the debate, as it suggests plantations can increase preservation while making Canadian firms more profitable by reducing their forestry footprints.

To broadly capture the economics of priority-use zoning, the three studies in this thesis are conducted at different scales—the stand-, forest-, and international-level. We begin at the stand-level, where it is difficult to achieve a financially feasible intensive zone using native boreal tree species (Rodrigues et al. 1998). Since we wish to include intensive zones within our priority-use zoning system, we look at whether hybrid poplar plantations are financially viable. Next, we move to the forest-level by using a timber supply model to evaluate whether different policies encourage plantation forestry and/or priority-use zoning. Finally, our international-level analysis uses a multi-country regression model to explore whether forest preservation is determined by plantations.

More specifically, the stand-level analysis suggests that although a priority-use zoning system addresses many of the challenges facing Canada's forest industry, only exotic species are likely to produce positive financial returns at the stand-level. The financial analysis begins by using secondary data to estimate a yield curve for hybrid poplar in western Canadian boreal regions. We then use this yield curve, along with cost data from Alberta-Pacific Forest Industries, to develop a stand-level net present value model. Our financial analysis suggests that intensively managing hybrid poplar is in a financial “grey area”, and policy changes may be required before the forest industry transitions towards priority-use zoning. This finding leads to the next chapter, where we evaluate policies that might shift hybrid poplar from its financial “grey area,” and hence encourage priority-use zoning.

In the forest-level analysis we use a spatial timber supply model to evaluate how various policies affect priority-use zoning. Our model spatially allocates land to whichever land-use activity—natural regeneration, native plantations, hybrid plantations, or preservation—maximizes profits to the forestry firm. Some policies allow firms to combine private land plantations with public land; others allow firms to establish exotic plantations on public land. Some policies allow the combined public/private land base to maintain the maximum sustained yield of timber that was previously produced from only the public land; others allow firms to produce whatever sustainable harvest level is most profitable. Our findings suggest that each of these policies would increase preservation and profits to some extent. Given these apparent benefits, in the next chapter we look for international evidence of relationships between two types of zoning—specifically exploring whether or not plantations might lead to more preservation.

In the international-level analysis we use a multi-country regression model to estimate how plantations affect preservation, controlling for country size and other relevant factors. There is statistically significant evidence of income, trade, and institutional effects. The income effect suggests that there is an environmental Kuznets curve for forest preservation. In other words, as a country develops it appears to trade-off preservation for income until per-capita-income reaches approximately US$20 500, after which the country begins increasing preservation. The trade effect suggests that as a country imports more forest products, it tends to increase its forest preservation. The institutional effect suggests that democracies preserve more forest. But we could find no evidence of a positive technique effect, which suggests that plantations are not promoting preservation—i.e., priority-use zoning is not yet prevalent in the countries we looked at.

There are a number of limitations to this work, which suggest areas for further research. One limitation of the stand-level analysis is that the yield curve data were not collected by measuring the same stand of trees through their life cycle. Instead, the data are an aggregation of one-time measurements of groups of stands in the same age classes. Although we believe our yield curve represents an aggregate yield curve for western Canadian boreal regions, such aggregation reduces the certainty of our results. To remedy these data deficiencies, tree breeding programs will be an important area of future research.

Another financial factor that requires further study is the impact of carbon offsets. Since hybrid plantations are not yet "business-as-usual" in most of Canada, future plantations could be considered as sources for carbon offsets. More work is needed in developing policies and carbon accounting procedures to track such carbon flows. Selling carbon offsets could significantly improve the profitability of hybrid plantations, and hence could stimulate priority-use zoning.

Moving now to the forest-level analysis, one limitation is the absence of non-timber values in the objective function. Although there are policies which prevent the firm from exceeding its public land sustained yield harvest, the analysis fails to directly consider the social value of preservation, and simply attempts to maximize firm profits. An area of further research would involve the use of contingent valuation methods to estimate the non-timber values generated by increased preservation. One could also use benchmarks to help identify the relative value of preservation.

Further research could also study outside influences on timber production. For example, one could explore the impact of increasing bioenergy production on plantation establishment. It would also be useful to simulate how our results are impacted by various risks, such as those incurred by fire, insect, disease, and price changes.

Another area for further research would be to survey the general public regarding the social acceptability of the various policies. It is plausible that some social groups will not be willing to accept hybrid plantations on public land as an offset to increased preservation. Such survey data would be helpful in determining which of the policies would likely be most socially acceptable.

Also, it is likely that private agricultural land with differing soil productivity will have different procurement costs. Future research could attempt to quantify the different costs associated with the different qualities of private land.

Our analysis of the private land allowable cut effect (PLACE) policy suggests that combining private and public land activates the allowable cut effect (ACE), thus allowing a firm to increase its harvest of existing timber from public land because of the increased productivity of private land plantations. But these benefits to the ACE only arise because of the significant costs of the sustained yield constraint; and implementation of ACE policies may not be advisable because they might prolong the continuance of sustained yield policies (Luckert 2001). Future research could estimate the costs associated with sustained yield policies by analyzing priority-use zoning in the absence of sustained yield.

Finally, the international-level analysis is hampered by our reliance on a somewhat limited secondary dataset. Unfortunately, reliable data for the key variables do not exist for all countries. As public institutions in developing countries advance, we hope that internal data collection will improve to the point where a more thorough analysis can occur in the future.

To conclude, we summarize the results of our three studies: Although priority-use zoning could increase timber and non-timber benefits, there is little international evidence of it actually taking place. However, provincial governments could use any of the policies we suggest in the forest-level analysis to encourage zoning within Canada. Yet even with additional forest preservation, the use of hybrid plantations might be upsetting to some. Hence a rigorous public debate is warranted. Before reforming policy, decision makers must trade-off the environmental implications of exotic plantations with the potential gains from priority-use zoning. But we must be cognizant that a system championed by environmental scientists, priority-use zoning, could actually make money for the forest industry. Such a rarity might be as close to win-win as we can get.

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APPENDIX 3.1

This appendix contains a copy of input files used within the Woodstock forest management system for the modelling in Chapter 3. The majority of the model is redundant for all six policies. Indeed, the only unique modelling inputs are the optimization commands. We begin by listing the optimization commands for each of the six policies. Then we include the rest of the input commands, which are identical for all of the policies.

MSY policy: even-flow on public land; no exotics

Step 1 – maximize AAC

```
OPTIMIZE
; Optimize

*OBJECTIVE
_MAX totvolume 1.. _LENGTH

*CONSTRAINTS
_EVEN(pubvolume) 1.._LENGTH

*EXCLUDE
convertpri 1.._LENGTH
cut2convert 1.._LENGTH
cut2exoticpub 1.._LENGTH
```

Step 2 – maximize NPV

```
OPTIMIZE
; Optimize

*OBJECTIVE
_MAX dlogrevenue - dcutcost - dhaulcost - dconvertpricost - dcut2convertcost -
dlfncost - dplantcost - dexoticcost 1.._LENGTH

*CONSTRAINTS
_EVEN(pubvolume) 1.._LENGTH
```

```
pubvolume = 2.2e6 1.._LENGTH

*EXCLUDE
convertpri 1.._LENGTH
cut2convert 1.._LENGTH
cut2exoticpub 1.._LENGTH
```

PPZ policy: even-flow on public and private land equal to MSY policy; exotics on private land

```
OPTIMIZE
; Optimize

*OBJECTIVE
_MAX dlogrevenue - dcutcost - dhaulcost - dconvertpricost - dcut2convertcost -
dlfncost - dplantcost - dexoticcost 1.._LENGTH

*CONSTRAINTS
_EVEN(totvolume) 1.._LENGTH
totvolume = 10.854e6 1.._LENGTH

*EXCLUDE
cut2convert 1.._LENGTH
cut2exoticpub 1.._LENGTH
```

PLACE policy: even-flow on public and private land, but no volume constraint; exotics on private land

```
OPTIMIZE
; Optimize

*OBJECTIVE
_MAX dlogrevenue - dcutcost - dhaulcost - dconvertpricost - dcut2convertcost -
dlfncost - dplantcost - dexoticcost 1.._LENGTH

*CONSTRAINTS
_EVEN(totvolume) 1.._LENGTH

*EXCLUDE
cut2convert 1.._LENGTH
cut2exoticpub 1.._LENGTH
```

MSY-PLE policy: even-flow on public land; exotics on public land

Step 1 – maximize AAC

```
OPTIMIZE
; Optimize

*OBJECTIVE
_MAX totvolume 1.. _LENGTH

*CONSTRAINTS
_EVEN(pubvolume) 1.._LENGTH

*EXCLUDE
convertpri 1.._LENGTH
```

Step 2 – maximize NPV

```
OPTIMIZE
; Optimize

*OBJECTIVE
_MAX dlogrevenue - dcutcost - dhaulcost - dconvertpricost - dcut2convertcost -
dlfncost - dplantcost - dexoticcost 1.._LENGTH

*CONSTRAINTS
_EVEN(pubvolume) 1.._LENGTH
pubvolume = 26.687e6 1.._LENGTH

*EXCLUDE
convertpri 1.._LENGTH
```

PPZ-PLE policy: even-flow on public and private land equal to MSY-PLE policy; exotics on public and private land

```
OPTIMIZE
; Optimize

*OBJECTIVE
_MAX dlogrevenue - dcutcost - dhaulcost - dconvertpricost - dcut2convertcost -
dlfncost - dplantcost - dexoticcost 1.._LENGTH

*CONSTRAINTS
_EVEN(totvolume) 1.._LENGTH
```

```
totvolume >= 26.687e6 1.._LENGTH
```

PLACE-PLE policy: even-flow on public and private land equal to MSY-PLE policy; exotics on public and private land

```
OPTIMIZE
; Optimize

*OBJECTIVE
_MAX dlogrevenue - dcutcost - dhaulcost - dconvertpricost - dcut2convertcost -
dlfncost - dplantcost - dexoticcost 1.._LENGTH

*CONSTRAINTS
_EVEN(totvolume) 1.._LENGTH
```

That concludes the optimization inputs, which are unique for each of the policies. The rest of the modelling inputs, which are listed below, are the same for all the policies.

```
ACTIONS
; Actions

*ACTION cut2lfn Y harvest timber
*OPERABLE cut2lfn
? treednative ? ? vol >= 50

*ACTION cut2plant Y harvest timber
*OPERABLE cut2plant
? treednative ? ? vol >= 50

*ACTION cut2exoticpri Y harvest timber
*OPERABLE cut2exoticpri
private exotic ? ? vol >= 50

*ACTION cut2exoticpub Y harvest timber
*OPERABLE cut2exoticpub
public exotic ? ? vol >= 50

*ACTION convertpri Y convert forage TO plantation
*OPERABLE convertpri
private ag ? ? _AGE >= 1
```

```
          *ACTION cut2convert Y harvest timber and convert TO plantation
          *OPERABLE cut2convert
          public treednative ? ? vol >= 50


CONSTANTS

df 3.7%
price 48.69
logcost 3060
convertpricost 2906 ;land purchase ($1675) + establishment ($1406) – stumping ($175)
cut2convertcost 175 ;land procurement ($50) + conversion cost ($300) – stumping ($175)
lfncost 5
plantcost 930
exoticcost 1406; has $175 stumping
h1cost 0.7
h2cost 2.1
h3cost 3.5
h4cost 4.9
h5cost 6.3
h6cost 7.7
h7cost 9.1
h8cost 10.5
h9cost 11.9
h10cost 13.3


CONTROL

; Control
 *LENGTH 40

LANDSCAPE

; Landscape

*THEME Landtype
public
private

*THEME Crop
lfn
plant
exotic
ag
```

```
*AGGREGATE treednative
lfn plant

*THEME Site
g
m
f
u

*THEME Haulclass
h1
h2
h3
h4
h5
h6
h7
h8
h9
h10


LIFESPAN

; Lifespan
? ? ? ? 100

*FORMAT MOSEK


OUTPUTS

; Outputs

*OUTPUT pubvolume Harvest volume
  *SOURCE cut2lfn vol + cut2plant vol + cut2convert vol + cut2exoticpub vol

*OUTPUT privolume Harvest volume
  *SOURCE cut2exoticpri vol

*OUTPUT cut2convertvol
  *SOURCE cut2convert vol

*OUTPUT totvolume Harvest volume
  *SOURCE cut2lfn vol + cut2plant vol + cut2convert vol + cut2exoticpub vol +
cut2exoticpri vol
```

```
*OUTPUT cut2lfnarea
 *SOURCE cut2lfn _AREA

*OUTPUT cut2plantarea
 *SOURCE cut2plant _AREA

*OUTPUT cut2convertarea
 *SOURCE cut2convert _AREA

*OUTPUT cut2exoticpubarea
 *SOURCE cut2exoticpub _AREA

*OUTPUT cut2exoticpriarea
 *SOURCE cut2exoticpri _AREA

*OUTPUT cut2exotictotarea
 *SOURCE cut2exoticpri _AREA + cut2convert _AREA + cut2exoticpub _AREA

*OUTPUT cutarea
 *SOURCE cut2lfnarea + cut2plantarea + cut2exotictotarea

*OUTPUT exoticarea
 *SOURCE ? exotic ? ? _INVENT _AREA

*OUTPUT exoticprivate
 *SOURCE private exotic ? ? _INVENT _AREA

*OUTPUT exoticpublic
 *SOURCE public exotic ? ? _INVENT _AREA

*OUTPUT lfnarea
 *SOURCE public lfn ? ? _INVENT _AREA

*OUTPUT plantarea
 *SOURCE public plant ? ? _INVENT _AREA

*OUTPUT convertpriarea
 *SOURCE convertpri _AREA

*OUTPUT convertpricost
 *SOURCE convertpriarea * #convertpricost

*OUTPUT dconvertpricost
 *SOURCE convertpricost * discfact
```

```
*OUTPUT cut2convertcost
 *SOURCE cut2convertarea * #cut2convertcost

*OUTPUT dcut2convertcost
 *SOURCE cut2convertcost * discfact

*OUTPUT lfncost
     *SOURCE cut2lfnarea * #lfncost

*OUTPUT dlfncost
     *SOURCE lfncost * discfact

*OUTPUT exoticcost
     *SOURCE cut2exotictotarea * #exoticcost

*OUTPUT dexoticcost
     *SOURCE exoticcost * discfact

*OUTPUT plantcost
 *SOURCE cut2plantarea * #plantcost

*OUTPUT dplantcost
 *SOURCE plantcost * discfact

*OUTPUT cutcost
 *SOURCE cutarea * #logcost

*OUTPUT dcutcost
 *SOURCE cutcost * discfact

*OUTPUT logrevenue
 *SOURCE totvolume * #price

*OUTPUT dlogrevenue
 *SOURCE logrevenue * discfact

*OUTPUT haulcost
 *SOURCE totvolume * haulc

*OUTPUT dhaulcost
 *SOURCE haulcost * discfact

*OUTPUT NPV
 *SOURCE dlogrevenue - dcutcost - dhaulcost - dconvertpricost - dcut2convertcost -
dlfncost - dplantcost - dexoticcost
```

```
*OUTPUT oldgrowtharea
 *SOURCE public treednative ? ? @AGE(27..1000) _INVENT _AREA


TRANSITIONS

; Transitions

*CASE _DEATH
*SOURCE ? ? ? ?
*TARGET ? ? ? ? 100

*CASE cut2lfn
*SOURCE ? ? ? ?
*TARGET ? lfn ? ? 100

*CASE cut2plant
*SOURCE ? ? ? ?
*TARGET ? plant ? ? 100

*CASE cut2exoticpri
*SOURCE ? ? ? ?
*TARGET private exotic ? ? 100

*CASE cut2exoticpub
*SOURCE ? ? ? ?
*TARGET public exotic ? ? 100

*CASE convertpri
*SOURCE private ag ? ?
*TARGET private exotic ? ? 100

*CASE cut2convert
*SOURCE public treednative ? ?
*TARGET public exotic ? ? 100


YIELDS

; Yields

*Y ? lfn g ?
vol 1  0  0  0.4  2.8  8.8  18.6  31.4  46.2  62  78.3  94.5  110.4  125.7  140.3  154.3
    167.5  180  191.8  202.9  213.4  223.3  228.8  231.8  232.5  231.4  227.3  216.8
    202.3  185.3  165.8  145.3  124.8  104.3  83.8  63.3  42.8  22.3  1.8  0
```

```
*Y ? plant g ?
vol 1  0  0.5  8.1  28.9  58.5  91.3  123.6  153.9  181.4  206  228  247.6  265.1  280.7
     294.7  307.2  318.6  328.8  338.1  346.6  354.4  359.9  362.9  363.5  362.5  358.4
     347.9  333.4  316.4  296.9  276.4  255.9  235.4  214.9  194.4  173.9  153.4  132.9
     112.4  91.9  71.4  50.9  30.4  9.9  0

*Y ? exotic g ?
vol 1  16.5  120.1  196.3  240.8  268  285.9  298.2  307.1  312.9  314.3  313.2  309.1
     298.2  268.2  213.2  133.2  28.2  0

*Y ? lfn m ?

vol 1  0  0  0.2  1.8  5.9  12.8  22  32.9  44.6  56.9  69.2  81.3  93.1  104.4  115.3
     125.7  135.5  144.8  153.6  162  169.9  175.4  178.4  179.1  178  173.9  163.4
     148.9  131.9  112.4  91.9  71.4  50.9  30.4  9.9  0

*Y ? plant m ?

vol 1  0  0.3  4.9  18.5  39.1  62.8  86.9  109.9  131.1  150.5  167.9  183.6  197.8
     210.5  222  232.3  241.7  250.3  258  265.2  271.7  277.2  280.2  280.8  279.8
     275.7  265.2  250.7  233.7  214.2  193.7  173.2  152.7  132.2  111.7  91.2  70.7
     50.2  29.7  9.2  0

*Y ? exotic m ?

vol 1  3.2  57  116.7  157.6  184.6  203  216.2  225.8  231.7  233.2  232.1  228  217.1
     187.1  132.1  52.1  0

*Y ? lfn f ?

vol 1  0  0  0.1  1  3.4  7.6  13.4  20.4  28.1  36.4  44.8  53.2  61.5  69.5  77.3  84.8
     91.9  98.7  105.2  111.4  117.2  122.7  125.7  126.4  125.3  121.2  110.7  96.2
     79.2  59.7  39.2  18.7  0

*Y ? plant f ?

vol 1  0  0.1  2.2  9.4  21.3  36  51.6  67.1  81.9  95.6  108.3  119.9  130.5  140.2  149
     157  164.4  171.1  177.3  183  188.3  193.8  196.8  197.4  196.4  192.3  181.8  167.3
     150.3  130.8  110.3  89.8  69.3  48.8  28.3  7.8  0

*Y ? exotic f ?
vol 1  0.4  18.4  51.6  80.9  103.1  119.7  132.3  141.9  149.2  150.8  149.8  145.7  134.8
     104.8  49.8  0

*YT ? ? ? ?
discfact _DISCOUNTFACTOR(#df,5,half)
```

```
*YT ? ? ? h1
haulc 1 #h1cost

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*YT ? ? ? h7
haulc 1 #h7cost

*YT ? ? ? h8
haulc 1 #h8cost

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haulc 1 #h9cost

*YT ? ? ? h10
haulc 1 #h10cost


AREAS

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APPENDIX 4.1

Country	*Preserved* (000 ha)	*LandArea* (000 ha)	*Forestry/Y*	Y/Pop_{00} (US$)	$(Y/Pop_{00})^2$ (US$)^2	$\ln(M^F)$ (mill. US$)	*Polity*
Japan	1757.913	37652	0.009117	25924	672053776	9.498069	10
Turkey	194.275	76963	0.007565	7414	54967396	7.131454	7
Australia	23335.389	768230	0.009459	27193	739459249	7.478073	10
New Z.	1660.714	26799	0.039334	20008	400320064	5.579413	10
Bulgaria	1391.13	11055	0.007321	6356	40398736	4.836829	8
Denmark	93.275	4243	0.009925	28539	814474521	7.454331	10
France	2746.039	55010	0.007079	23614	557620996	8.974179	9
Greece	1047.309	12890	0.004992	15558	242051364	6.767351	10
Hungary	368	9234	0.009624	11063	122389969	6.529233	10
Ireland	6.59	6889	0.006870	27197	739676809	6.593232	10
Italy	1880.564	29406	0.010121	22876	523311376	8.964965	10
Netherlands	88.5	3392	0.007249	25759	663526081	8.417187	10
Norway	2296.812	30683	0.011429	32057	1027651249	6.928877	10
Poland	1420.379	30442	0.013277	9661	93334921	7.246297	9
Portugal	634.218	9150	0.021218	17089	292033921	6.883297	10
Romania	477.152	23034	0.019924	5024	25240576	5.244864	8
Russian Fed.	25541.76	1688851	0.007539	9996	99920016	5.961291	7
Spain	3420.06	49945	0.011485	19036	362369296	8.375231	10
Switzerland	43.164	3955	0.014742	28209	795747681	7.413899	10
UK	896.874	24160	0.007699	24252	588159504	9.105666	10
USA	66667.935	915895	0.012761	35619	1268713161	10.154471	10

Country	*Ownership* (%)	*Forestry/ForLand* (000 US$/ha)	*Plantation* (000 ha)	*ForLand* (000 ha)	Y/Pop_{95} (US$)	$(Y/Pop_{95})^2$ (US$)^2	Gravity instrument
Japan	41.9	1.80540675	10682	24081	22967	527483089	5.47
Turkey	99.9	0.12753056	1854	10225	6085	37027225	32.57
Australia	72	0.02170973	1043	154539	21771	473976441	4.07
New Z.	63.4	0.23118550	1542	7946	17075	291555625	8.19
Bulgaria	91.6	0.02168022	968.5	3690	6651	44235801	31.12
Denmark	28.4	3.00659341	340	455	23119	534488161	30.89
France	26	0.53770941	961	15341	19791	391683681	15.26
Greece	77.5	0.13559322	120	3599	12218	149279524	27.01
Hungary	60.5	0.20380435	136.2	1840	8537	72880369	26.92
Ireland	46.6	0.88163885	590	659	16979	288286441	33.08
Italy	35	0.96670999	133	10003	19783	391367089	13.97
Netherlands	49.7	6.35466667	100	375	20607	424648449	35.84
Norway	14	0.18403248	300	8868	23016	529736256	23.54
Poland	83.2	0.20327180	39	9047	7204	51897616	13.84
Portugal	7.3	0.52864157	834	3666	12907	166590649	18.78
Romania	94.3	0.10452854	91	6448	4700	22090000	18.8
Russian Fed.	100	0.00205546	17340	851392	7069	49970761	3.68
Spain	30	0.40459290	1904	14370	15992	255744064	12.38
Switzerland	68	2.77648040	4	1199	24110	581292100	32.57
UK	36.2	3.47029349	1928	2794	19188	368179344	13.47
USA	42.4	0.51342741	16238	225993	27895	778131025	2.56